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# INTEGRATING LEAN AND SIX SIGMA FOR OPTIMUM MANUFACTURING PERFORMANCE

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**Abstract**: Recent manufacturing industry reports and research indicate that the majority of companies seeking to achieve world class performance, or improve their business performance in an increasingly competitive market, have not been able to change at a reasonably fast rate towards achieving their performance targets such as lead time, delivery, quality and cost. This paper attempts to study the effectiveness of lean and six sigma, two of the most popular performance improvement methodologies used by manufacturers today, and highlights their strengths and weaknesses, investigates the rationale behind combining them. The study also explores the most effective way of integrating the two philosophies to achieve improvement at a fast rate. Most published research on integrating lean and six sigma have been only descriptive. Descriptive research is an important step towards explaining the rationale of integrating lean and six sigma, however, empirical research on lean six sigma is characterised by lack of attention to implementation know how, resulting in the need to focus on the operational side.

## 1. Introduction:

The fast pace of modern industrial society does not allow the luxury of improvements by trial and error. This has created the need for a modern and structured process of improvement. Two major pillars of structured process improvement grew up separately in the last half of the 20th century and have come to be known as 'lean' and 'six sigma'. Lean improvements focus on process speed and waste removal while six sigma, like its predecessor TQM, focuses on the removal of process variation that lead to defects (George, 2002).

Today's markets are highly dynamic and customers are demanding ever higher performance from manufacturers (George, 2002). Globalisation has also increased business competition to unprecedented levels.

## 2. Lean six sigma:

Lean six sigma is a methodology that aims to maximise shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed and flexibility. Securing these objectives will lead to high returns on invested capital. The theory ties up logically when we understand that the lean philosophy with its waste elimination focus, reduced lead time, work place organisation, and visual management orientation, makes it much easier to expose hidden problems. Lean and six sigma together provide the tools and techniques to solve problems and achieve significant improvements across the company faster (George, 2002). The challenge now is to combine lean and six sigma effectively such that together they will provide better results than those achieved when the two tools are applied individually.

## 3. Popularity of lean six sigma:

Recent reports (Jiju et al, 2006) revealed that only 6% of UK small and medium enterprise manufacturers are using lean six sigma (Figure.1). This shows clearly that lean six sigma is still a new methodology that has not yet gained popularity and confidence from manufacturers which indicates the need for more research to give the manufacturer more confidence.

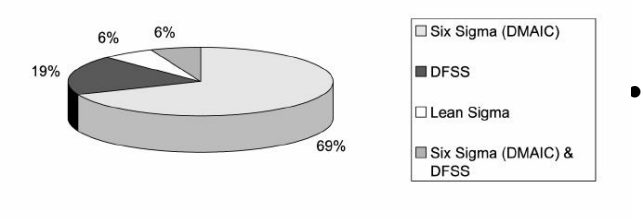


Figure1: Six sigma methodologies used by SMEs. Source: International Journal of Quality & Reliability Management Vol. 22 No. 8, 2005 pp. 860-874

### 3.1. Existing models of lean six sigma:

Lately a number of companies worldwide came to realise the advantage of applying lean and six sigma together. This is because companies started six sigma and spent several months trying to reduce lead-time, only to realize that they were reinventing lean (George, 2002). Most published literature suggests that lean and six sigma are a perfect combination for process improvement (George, 2002; Arnheiter et al, 2005; Dahlgaard-Park et al, 2007; Bevan et al, 2005; Rowlands et al, 2004; Arthur et 2007), in fact there is evidence that lean and six sigma have been used selectively or complimentary by many companies such as:

- General Electric, one of the six sigma pioneers is now adopting a lean six sigma programme to achieve rapid transformation change at low cost (Bevan et al, 2005).
- Gencorp Aero concluded that lean and six sigma combine well together and their approach to this is that defective products or services are identified as a form of waste which must be removed using six sigma tools.
- Pitco Frialator has been successful in implementing an improvement program called 'lean sigma'. They implemented lean first for about two years then they started six sigma to add the quality improvement edge to enable them to improve their product and quality even further.
- Honda uses basic lean tools for solving production problems, preventing re-occurrence, and improving processes in general, but they also use six sigma when there is a need to determine process high impact factors and to demonstrate that the improvements they introduced have actually added value to their processes.
- Siebe Appliance Controls used a different approach to the combined implementation of lean and six sigma. They started with six sigma, then Kaizen. They believe that it is important to improve the process first, and then increase its efficiency.
- American Racing, unlike Siebe Appliance believes that lean should be employed first because lean will eliminate non-value adding operations that six sigma may want to optimize. Also lean initiatives will put standardisation into place, which is an essential starting point for six sigma.

Eliminating waste and non-value added processes using lean first and then making the enduring processes robust by using six sigma appears to be a sensible order.

## 4. Need for integrating lean and six sigma:

Lean can learn from six sigma the scientific approach to quality. Decisions should be based on data. Despite the fact that lean with its zero quality control tools (ZQC) enables early discovery of defects and prevent producing more, yet stopping production when an error is detected creates waste. Since processes are synchronised by the pull system, these stoppages although they prevented more defects, can lead to delivery failure or the need for overtime to recover. Reworking or scrapping defective products however few they are, also creates more waste. Likewise, six sigma organisations can get to the point of diminishing returns by not using certain lean principles such as setup time reduction, small batches, and flow of material, value stream mapping and total productive maintenance (TPM) that increase speed and reduce lead time. It is within lean management capacity that six sigma organisations learn how to improve their value adding time and reduce lead time (Arnheiter and Maleyeff, 2005).

Bevan et al (2005) think that 'combining common sense (lean) and common science (six sigma) offers the potential to achieve uncommon results'. Table.1 summarises why lean and six sigma need each other.

The integration of lean and six sigma is needed because:

- Lean cannot bring processes under statistical control.
- Lean is unable to take advantage of all opportunities of cost savings that exist in eliminating quality defects.
- Six sigma is a powerful tool that needs lean to provide visibility to spot problems as soon as they occur.
- Six sigma alone cannot significantly improve lead time.
- Six sigma cannot improve production flexibility.
- Integrating lean and six sigma, improves the problem solving capability as improvement projects no longer require problem definition.

| Lean need for six sigma | Six sigma need for lean |
|---|---|
| Lean need a project management approach that identify projects through all their implementation stages. | Six sigma needs the overall system approach in order to improve process speed/cycle time and total lead time. |
| Lean need to make better use of data, i.e. collect data, analyse them and make decisions based on evidences. | Six sigma needs the value stream approach to identify other sources of waste apart from those caused by variation. |
| Lean can improves quality further by identifying and eliminating variation. | Six sigma can achieve better results and quicker if none value-added activities and waste are removed from processes first. |
| Lean may frequently need to deals with and optimise individual processes associated with critical quality characteristics. | Six sigma needs the lean rapid action flexibility (Kaizen) to deal with urgent or simple issues that does not need to be subjected to the DMAIC process. |

Table1: Lean and six sigma compliment each other

## 5. Benefits of integrating lean and six sigma:

In manufacturing the main customer satisfaction drivers are: quality, cost, and on-time delivery. Thus the three major objectives are:

1. Improving product quality by better understanding of customer needs and creating the process that meet these needs.
2. Reducing cost by eliminating waste and better utilization of resources.
3. Reducing lead-time by improving process design, eliminating all sorts of waste and maintaining continuous material flow.

By integrating the two tools, the end result is expected to be the achievement of all three objectives as shown in Figure. 2.

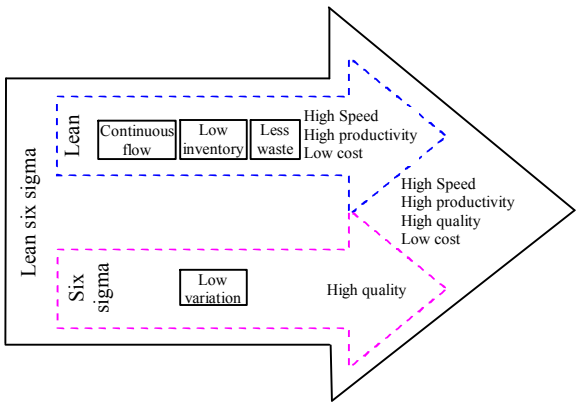


Fig2. Integrating lean and six sigma

Lean six sigma organisations can take advantage of the strengths of the two tools, by adopting three primary principles from lean and another three principles from six sigma (Arnheiter and Maleyeff, 2005).
From lean:

1. Maximising value adding content.
2. Evaluating incentive systems to ensure global optimisation.
3. Decisions driven by customer satisfaction.

From six sigma:

1. Data driven decision making and scientific based changes.
2. Quality improvement based on reducing variation.
3. Company wide highly structured education and training approach.

Arthur (2007) believes that with lean six sigma companies can:

1. Double their speed without working harder; this will come as a result of eliminating delays in processes.
2. Double their quality by reducing defects and variations by 50% or more. Lean alone can reduce defects by 50% and when six sigma is added to it, further quality improvements could be achieved when variation is removed.
3. Improve their profits as a result of eliminating the cost of fixing problems.

Furthermore, combining lean and six sigma enables achieving improvement at lower cost (Bevan et al, 2005).

### 5.1. Quality:

Lean needs six sigma to improve quality to a higher level. Lean on its own, improves quality but only to a certain limit. This is because the lean approach to quality does not address natural process variation directly, but through preventing conditions that can lead to discrete events on the process output. Lean uses standardisation to create standard conditions that lead to consistent work practices which minimise the effect of noise on the process (Breyfogle et al, 2001). To ensure consistent performance of individuals, equipment, work practices and quick feedback of information between downstream and upstream operations, tools such as Standardisation, Cellular Manufacturing, TPM, Error Proofing, One Piece Flow, First In First Out (FIFO) and Automation are used.
Furthermore the lean emphasis of the zero quality control (ZQC) means attribute inspection is used. Inspection is performed using a pass/fail criteria related to upper and lower control limits of the measured quality characteristic. This technique is quick, but since the actual measurement is not recorded the natural process variation is not understood and hence cannot be monitored or controlled, making it difficult to keep process variation within certain tolerance limits or evenly distributed around nominal targets. With simple products this may be fine, but with more complex products where tolerance can clash, this can cause quality and reliability problems. If the product is characterised by sensitive operations such as

patient critical medical devices, failure may lead to loss of human life. In other products such as nuclear plants or passenger aeroplanes, failure can cause disasters (Arnheiter and Maleyeff, 2005). It will be unacceptable if only 99% of flights landed safely (Babu, 2006). Without six sigma, monitoring variation and controlling it becomes difficult.

Six sigma is particularly important for manufacturing processes that are characterised by high speed and high volume outputs. This is because with a high speed high volume output, poor process yield can result in considerably high amounts of defective products. It should be noted that eliminating waste does not only improve speed but also quality by reducing opportunities of making errors.

## 5.2. Cost:

By integrating lean and six sigma, costs can be reduced. This is because simple defects/errors and delays in the manufacturing operation contribute to a significant amount of business expenses. Cumulative cost of delays and defects can add 25 to 40% of business expenses (Arthur, 2007). Figure 3 shows effect of process output in business performance.

Lean is well known for its effectiveness in reducing cost by eliminating all sorts of waste (inventory, transportation, waiting, walking, defects, over processing, over producing).

However, as lean cannot completely eliminate quality related waste, it follows that by combining lean and six sigma there is a greater opportunity for reducing cost and multiplying the gains. The research by Anbari and Kwak, (2004) show that six sigma was able to make huge savings for companies by targeting just quality related waste, e.g. six sigma saved $15 billion for Motorola in 11 years, $2 billion for General Electric in 1999, $1.2 billion for Honeywell and €30 millions savings and increase in revenues in the first 10 months for Telefonica De Espana.

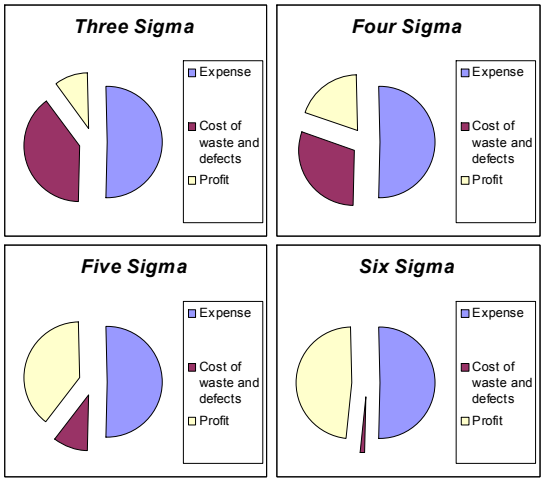


Fig.3 Cost of poor process performance

## 5.2. Speed:

Six sigma does not directly address process lead time, this is because value stream improvement is not a clear objective of six sigma, so the lack of improvement in the lead-time in companies who follow six sigma is understandable. Any improvements in lead time are by products (George, 2002). These companies also generally achieve marginal improvement in work in progress (WIP) and finished goods inventories. Fortunately, these six sigma weaknesses are what lean is good at. The lean tools can improve process speed and lead time dramatically. Table 1 shows a typical performance improvement as a result of introducing lean by a pressure sensor manufacturer (Smith, 2002).

| | Dec 96 | Sep 97 | Change |
|---|---|---|---|
| Lead Tim | 12 days | 6.5 hours | -93% |
| WIP | 9 hours | 1.5 hours | -83% |
| Finished Goods | 96 items x 318 units | 38 items x 76 units | -60% (items) -76% (units) |
| Overtime | 10 hours/week/person | 5 hours/week/person | -50% |
| Productivity | 2.4 pieces/man-hour | 4.5 pieces/man-hour | +180% |

Table 1. Performance improvement as result of introducing lean. Source: International Conference on Production Research, ICPR Americas '02 November 14, 2002.

This particular attribute of lean can be improved further by combining lean and six sigma since high quality enables further elimination of none value adding activities related to poor quality such as inspection and correction of defective products which cannot be drastically eliminated without a high quality level such as that provided by six sigma.

## 6. Integrating lean and six sigma for maximum manufacturing benefit:

The biggest opportunities of improvement are in the manufacturing operation. Hence for maximum benefit, lean and six sigma integration need to be at the core business process or the shop floor, this is because the manufacturing operation has a direct effect on customer satisfaction from all aspects of cost, quality and delivery (Arthur, 2007). Black (1991) is also of the opinion that the manufacturing function shapes the future of manufacturing business 'the market decide the price, manufacturer's behaviour decide the cost, and the difference is the profit'.
Spears and Bowen (1999) concluded that one of the three elements that made Toyota the most successful manufacturer in the world is the fact that the Toyota Production System (TPS) paid more attention to design, operation, flow-paths, connections and improvement of activities.

This conclusion is also supported by the results obtained from a survey conducted by researcher in 2008 (Shamou and Arunachalam, 2008) about implementation of lean and six sigma in the manufacturing sectors which included 25 manufacturers from the US, UK, Germany, Holland, China and Spain. The survey results have revealed the following facts:

- For 52% of lean manufacturers, the cost of poor quality constitutes 10 - 20% of their operational cost.
- 62% of lean manufacturers work at or below 95% process first time through.

Companies can save up to 20% of their expenses if they eliminate defects, increase process speed and reduce their lead time, all these required improvements are operation related (Shamou and Arunachalam, 2008). This implies that improvement work has to target all aspects of the daily repetitive manufacturing operation that starts with arrival of materials from suppliers and ends up with the shipment of finished products to the customers. To be able to make this 20% savings, the company's manufacturing operation must meet these conditions:

1. Defect free process
2. High value adding operation
3. High process flexibility
4. Continuous material flow
5. On demand production

These five conditions agree with what George et al (2004) described as the fives laws of lean six sigma:

1. Customer needs define quality and priority of improvement projects
2. Speed of the process is proportional to its flexibility (setup time)
3. Focus improvement issues on the few issues that have the maximum impact (20% to 80% law)
4. Speed of the process is inversely proportional to the amount of WIP in the process.

5. Product complexity affects the process cost more than poor quality or slow speed does.

As previously suggested, the integration of lean and six sigma has to focus on all aspects that help to satisfy the five conditions listed here. The required integration can be achieved by adopting lean as the manufacturing system that identifies the physical layout of the manufacturing facility as well as the production system features. Many opportunities exist to improve operations through the use of lean concepts, but the best opportunity may lie in a facilities design project (Duggan, 1998). Six sigma on the other hand will be adopted as the main approach to manufacturing quality control.

The lean principles determine the following aspects:

1. Production facility layout (storage, paths, cells, material flow).
2. Flexibility (equipment, operators).
3. Process design (waste free, design for effective manufacturing and assembly).
4. Supply and demand management.
5. Improvement of daily issues (Kaizen).

Six sigma controls and monitors quality as well as manages continuous improvement and is expected to provide the following:

1. Identifies individual processes associated with critical quality characteristics, and then improves quality further by eliminating variation.
2. Quality control based on data acquisition (not pass/fail attribute) and detecting hidden problems, group them into clear observable patterns, show current process performance and enables process control.
3. A project management approach that identifies high impact projects on strategic bases and manage them through all their implementation stages.

The implementation process goes through the following steps:

1. Define value from customer view.
2. Establish a layout that supports optimum material flow and minimum waste.
3. Design the process support manufacturing and assembly to improve quality.
4. Apply cellular manufacturing principles to increase value adding and eliminate waste (value stream analysis).
5. Standardise conditions (training, error proofing, FIFO, one piece flow, TPM)
6. Monitor and optimise processes (remove variation).
7. Improve flexibility (group technology, quick setup, cross training, TPM)
8. Maintain material flow (pull system, Kanban, value stream analysis)
9. Continue to improve efficiency and quality (Kaizen, six sigma)

## 7. Identification of improvement opportunities:

Continuous improvement is one of the basic lean principles. To identify improvement opportunities in lean environments is usually not an issue; the issue is to identify the best ideas from among a long list (George et al, 2004). Integrating lean and six sigma will make this challenge easier. Six sigma with its close linkage to strategic planning and notable interest in increasing share holders value is more than capable of identifying the best improvement project. The best project is usually the one that has the biggest business return. For strategic planning, the project identification is a top down process. The board of directors or top management usually identify the general goals for the organisation. Once this stage is completed the core business value stream has to be

reviewed to identify parts of the value stream that affect each corporate goal.

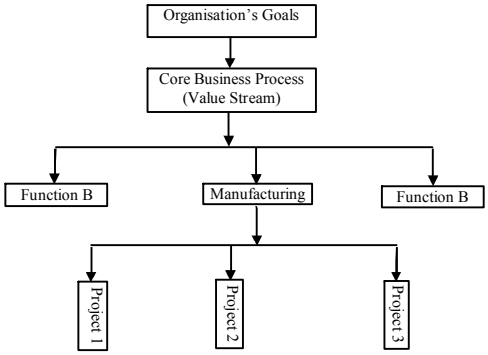


Fig3. Project identification process

These business goals are then broken down into business objectives for each business function that influence the goal (Fig3).
The fact that six sigma is a general business improvement tool that aims at increasing shareholders value (George, 2002), makes six sigma the most sensible approach to follow to identify and prioritise improvement projects in lean six sigma environments.

## 8. Management of improvement project and problem solving:

Establishing a standard manufacturing environment is important for reducing variation, the approaches to this are standardisation, problem solving (countermeasures) to defend the system. Problem solving is also a very effective way of learning. Smith (2002) reported that one of the distinguished features of the Toyota Production System is that employees learning occurs through actually doing the work, finding and solving problems.
Kaizen and DMAIC (define, measure, analyse, improve, control) are the main problem solving tools in lean and six sigma organisations respectively. Integrating lean and six sigma improves problem solving capabilities and increases the number of problem solving tools at our disposal as well as increasing flexibility to deal with all kind of problems encountered in manufacturing environments. Kaizen is used more frequently than six sigma to deal with everyday problems and problems that need a quick fix. However, because Kaizen uses basic tools and common sense, it is not suitable for complex problems or projects.
The six sigma DMAIC on the other hand, which is a problem solving discipline that provides a structure for the team to follow, is a powerful tool that can deal with complex problems that requires more data and deep analysis. The process normally takes time and considerable resources to apply, hence it is only feasible when gains are expected to out-weigh the investment.
Figure.4 suggests a process flow for the decision making process which starts by identifying the problem or project upfront. Based on the nature of the problem a decision will be taken about which approach to follow KAIZEN or DMAIC. For urgent problems that cannot wait for weeks and months of data collection and analysis, Kaizen might be the best option.

## 9. Conclusion:

Integrating lean and six sigma produces better performance results in quality, cost and lead time. To take full advantage of lean six sigma, it will need to be applied at both strategic and operational levels. However the application at operational level will result in faster and more tangible cost reduction.
For ongoing businesses, successful implementation of lean six sigma cannot be achieved without radical restructuring of the shop floor manufacturing system to

incorporate all fundamentals of lean and six sigma. This is equally applicable for existing and new business with the slight difference that for new businesses the manufacturing system is to be designed to incorporate the fundamentals of lean and six sigma from day one. The fundamentals that create the lean six sigma manufacturing system are: establishing a layout that supports minimum waste, defining value, designing processes that only add value, monitoring and optimising processes that affect critical quality characteristics, maintaining material flow by adopting a pull system driven by customer demand.

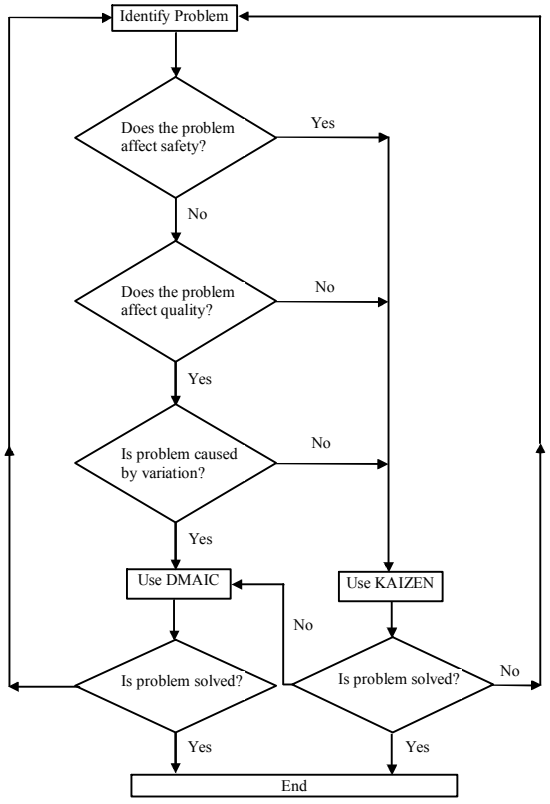


Fig. 4 What problem solving approach KAIZEN or DMAIC.

Process variation not only affects manufacturer's ability to meet customer specifications but also in meeting customer demands as variation can cause delays which in-turn can eventually lead to delivery failures.

By integrating lean and six sigma on the shop floor, manufacturers stand a good opportunity of saving considerable resources which can be wasted in defects and delays.

Companies can significantly improve their profit margin if they can save these resources. Saving these significant resources constitutes an important source of cash flow that every business needs.

Integrating lean and six sigma improves problem solving flexibility. It provides two approaches to choose from when dealing with problems Kaizen and DMAIC, depending on the nature of the problem or project.

Flexibility will be improved further by applying the lean principles of people involvement, i.e. the involvement of people who are mostly affected by identifying and solving the problem.

## 10. References:

Arnheiter, E., Maleyeff, J., 2005. The integration of lean management and six sigma. The TQM Magazine Vol. 17 No. 1, 2005 pp. 5-18.

Anbari, F., Kwak, Y., 2004. Success factors in managing six sigma. Project Management Institute Research Conference, London, UK, July 11-14, 2004.

Antony, J., Kumar, M., Madu, C., 2005 Six sigma in small- and medium-sized UK manufacturing enterprises Some empirical observations. International Journal of Quality & Reliability Management Vol. 22 No. 8, 2005 pp. 860-874.

Baudin, M. (2002), Lean Assembly. The Nuts and Bolts of Making Assembly

Operations Flow, Productivity Press, New York, NY.

Bevan, H., Westwood, N., Crowe, R., O'Connor, M. 2005. Lean six sigma: Some basic concepts. NHS Institute for Innovation and Improvement, 2005.

Breyfogle, F., 2005. Common Problems. Six sigma forum magazine. Copyright 2005 ©. Smarter Solutions, Inc.

Breyfogle, F., 2003. The Ties that Bind lean and six sigma. Society of Manufacturing Engineers publications 2003 N0.2095.

Michel Baudin, B., 2002. Six sigma and lean manufacturing. Lean Directions: The E-Newsletter of lean Manufacturing. July 2002.

Breyfogle, F., Cuppelo, J., Medows, B., 2001. Managing six sigma: A practical Guide to Understanding, Assessing, and Implementing the Strategy That Yields Bottom-Line Success.

Black, J., 1991. The Design of the factory with a future. McGraw Hill

Dershin, H., 2004. Lean and six sigma – The Twin have met. Strong Management Consultants – 2004.

Flott, L., 2000. Six sigma controversy quality control. 2000, p 43-45.

George, M., 2002. Lean six sigma, combining six sigma quality with lean speed. McGraw-Hill 2002.

George, M., Rowlands, D., Kastle, B. 2004. What is lean six sigma. McGraw Hill.

Arthur, J., 2007. Lean six sigma Demystified: A self teaching guide. McGraw Hill.

Pyzdek, T., 1999. Why six sigma is not enough. Quality Digest pp. 26.

Smith, J., 2002. Secrets of the REAL Toyota Production System. International Conference on Production Research, ICPR Americas '02 November 14, 2002.

Spear, S., Bowen, K., 1999. Decoding the DNA of the Toyota Production System. Harvard Business Review 99509. 1999.

Shamou, M., Arunachalam, S., 2008. Investigating implementation of lean and six sigma: Empirical Study. Part of an ongoing PhD research at University of East London.

Upton, M., Cox, C., 2002. Lean six sigma: A Fusion of Pan-Pacific Process Improvement. George Group publications 2002.