

## **Six Sigma: A Retrospective and Prospective Study**

**Weiyong Zhang** <sup>†</sup>

Assistant Professor

wzhang@vcu.edu

Phone: (804) 828-3196

Department of Management

School of Business

Virginia Commonwealth University

301 West Main Street

Richmond, VA 23284-4000

**Arthur V. Hill**

John and Nancy Lindahl Professor

ahill@umn.edu

Phone: (612) 624-4015

Operations and Management Science Department

Curtis L. Carlson School of Management

University of Minnesota

3-150 Carlson School of Management Building

321 19-th Avenue South

Minneapolis, MN 55455 USA

**Glenn H. Gilbreath**

Professor

ghgilbre@vcu.edu

Phone: (804) 828-6468

Department of Management

School of Business

Virginia Commonwealth University

301 West Main Street

Richmond, VA 23284-4000

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<sup>†</sup> *Corresponding author*

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### **Abstract**

Since its inception at Motorola, Six Sigma has been widely adopted by many different types of organizations. The effectiveness of Six Sigma is well supported by anecdotal evidence. However, academic research on Six Sigma is still in its early stage. This paper first reviewed the current literature on Six Sigma, and then performed a critical analysis of Six Sigma in light of the management literature. The review and analysis suggested that Six Sigma is best defined as a new approach to quality management. Consequently, Six Sigma provides an interesting context for a number of research questions. We then discussed these prospective research questions. This study laid a foundation for future research on Six Sigma.

*Keywords:* Six Sigma; literature review; future research

# **Six Sigma: A Retrospective and Prospective Study**

## **1. Introduction**

Six Sigma is an important advance in quality management and process improvement in the last two decades. Six Sigma has gained wide popularity in various types of organizations since the 1990s. Most Fortune 500 companies have adopted Six Sigma (Goh, 2002). Rich anecdotal evidences showed that Six Sigma can help firms achieve significant performance improvement. For example, Motorola reported \$16 billion benefits from Six Sigma for the period of 1986-2001 (Eckes, 2001; Hendricks and Kelbaugh, 1998; Motorola, 2003). Other firms such as General Electric (GE), Honeywell, and 3M reported similar results (3M, 2003; Arndt, 2004; GE, 2002; Honeywell, 2002). The benefits of Six Sigma include but are not limited to cost reduction, customer satisfaction improvement, and sales revenue growth (Pande et al., 2000).

Comparing to its impressive track records in practices, research on Six Sigma was at a rather low level due to several reasons. Some scholars view Six Sigma as applying a set of statistical tools and techniques (e.g., Das et al., 2008). Naturally it is not a serious research subject. Others believe that Six Sigma is simply a repackaging of the well-known total quality management (TQM) program, i.e., “old wine in new bottle” (e.g., Beer, 2003). Lastly, there is a collective concern that Six Sigma might be a management fad. Apparently, studying a management fad is not likely to make significant contributions to the literature (Abrahamson, 1996). However, as more and more Six Sigma success stories were published, there is a need to revisit the set perceptions about Six Sigma. Consequently, research interest on Six Sigma began to soar (Goh, 2002).

Recently, several papers on the subject of Six Sigma have appeared in top journals. But overall, research on Six Sigma is still lagging behind.

Lack of research on Six Sigma has two significant implications. First, the concern of Six Sigma being a management fad has prevented many scholars from conducting rigorous research on Six Sigma. However, if Six Sigma is not a management fad, this means we have lost precious opportunities to advance knowledge. Ironically, the question whether Six Sigma is a management fad can only be truly answered by rigorous research. Second, Six Sigma implementation generally requires millions of dollars of investment and years of effort. Practicing managers need scientific knowledge to guide their Six Sigma implementation effort. Without scientific research, the daunting task of exploring effective implementation method is at the mercy of trial and error, leading to higher chance of Six Sigma failure. Therefore, the urgency of conducting more research on Six Sigma can be clearly seen.

For research on Six Sigma to make solid progress, directions are needed. Since scientific research follows a cumulative tradition, it is necessary to first understand what has already been studied. Therefore, a vital first step is to gain an in-depth understanding of Six Sigma by reviewing the current literature. However, the lack of research on Six Sigma suggests only literature review is insufficient. A critical analysis of Six Sigma in light of the management literature was thus performed subsequently. This analysis identified a number of areas that could lead to fruitful research insights.

This paper is organized as follows. The second section provides an overview of Six Sigma. The section also argues that Six Sigma is not a management fad and it deserves serious research effort. Section 3 describes the literature review method.

Section 4 reports the overall impression of the current literature. The definition of Six Sigma is deliberated in Section 5. The distinctive elements of Six Sigma are summarized in Section 5 as well. Research issues surrounding Six Sigma are discussed in Section 6. Section 7 concludes the paper with a summary of the main findings and a discussion of contributions from this study.

## **2. Six Sigma**

### **2.1. Background**

Six Sigma was invented at Motorola in the 1980s (Barney, 2002; Delsanter, 1992). The invention was motivated by the high cost of poor quality discovered at Motorola. Like many companies at that time, it was as high as 15% to 20% of the sales revenue (Crosby, 1979). The production processes had low capability. A large portion of the products failed to meet customer requirement. This led to scrap, rework, field service, or return or recall if the product has been already shipped to the customers. Obviously, if Motorola can improve its process so that very few defective products are produced, the cost of poor quality can be reduced significantly. This will directly contribute to Motorola's bottom line (Pande et al., 2000). Motorola engineers hence proposed the concept of Six Sigma, which means achieving a quality standard of less than 3.4 defects per million opportunities (DPMO). This is a very high standard since the then industrial standard is about 35,000 DPMO (Bothe, 2002).

Motorola enjoyed the success brought by Six Sigma. Consequently, Six Sigma was promoted to many Fortune 500 companies in the 1990s where it also helped them achieve significant results. The list included famous companies such as AlliedSignal (now Honeywell), GE, and 3M. At the same time, Six Sigma also went through significant evolution. Particularly, GE enhanced Six Sigma with many new practices. GE later

claimed that Six Sigma has become an integral part of its business culture and strategy (Barney, 2002). GE's success further disseminated Six Sigma to small to medium sized businesses. Two decades since its inception, Six Sigma is no longer just a defect rate measure. It has a statistics core, a rigorous improvement method, and a unique set of practices (Breyfogle et al., 2001; Harry and Schroeder, 2000; Pande et al., 2000).

## **2.2. The management fad concern**

Rich anecdotal evidences about Six Sigma's effectiveness eventually alleviated scholar's concern that Six Sigma is a management fad. The lack of research on Six Sigma is largely explained by the concern. Studying a management fad will not make significant contributions. With time, the concern is alleviated by more and more anecdotal evidences. Six Sigma is unlikely a management fad for several reasons. According to Abrahamson (1996), management fads have some common characteristics. First, a management fad is usually short lived. But Six Sigma has outlived many management fads in the past two decades. Second, a management fad promises much but fails to deliver results. Six Sigma seems to be able to deliver results at many different places. Third, management fads are commonly perceived as industry norms and that is usually the main reason why firms adopt them. In contrast, the adoption of Six Sigma seems to follow a quite different pattern: Its adoption tends to be cross industry and the adoption decisions are mostly based on cost/benefits analysis. These all suggest that Six Sigma is unlikely a management fad but likely has something new that is worth studying.

## **3. The Literature Review Method**

We started with a review of the literature to gain an in-depth understanding of Six Sigma. We followed a structured method to review the literature. The first step is to define what the Six Sigma literature is. It is not a surprise that a huge amount of

materials are available due to Six Sigma's popularity. Most of them are highly practitioner oriented. We decided to include the practitioner's literature in the review because research on Six Sigma is still in its early stage. But our focus is clearly on the academic literature side.

The second step is to identify the content of the literature. Using keyword "Six Sigma", we searched three major databases: ABI INFORM, Business Source Premier, and Elsevier Science Direct. We then examined the search results to determine whether an article should be included in the academic literature or the practitioner's literature, or simply is irrelevant. For practitioner's literature, we also included published books on Six Sigma.

The search of the three databases (performed in November 2008) returned a total of 573 records from peer reviewed journals. We first removed irrelevant search records. Then we removed records not corresponding to a real article, for example, an editorial or a book review. After first screening, 507 articles remained in the list. Then we noticed that 386 articles are from journals that are clearly practitioner oriented: Quality Progress (194), Quality (81), ASQ's Annual Quality Congress Proceedings (36), and others (48). These articles were move to the practitioner's literature side, reducing the number of academic papers to 148. Then we performed a preliminary review to remove those are not academic research papers. On the other side, the preliminary review also led to the addition of several articles. These articles were not in the original list but they are found to be relevant to Six Sigma during the review. The final list includes 154 articles.

On the practitioner's literature side, we included both books and peer-reviewed journal articles. We searched books with "Six Sigma" in their title via Amazon.com.

The search returned 689 books. Since Amazon.com maintains a quite comprehensive list of books that have been published, it is unlikely that we may have missed an important title on Six Sigma. To be safe, we also examined web links called “publications” or “recommended readings” at a number of well-known sites for Six Sigma (e.g., isixsigma.com). We are confident to report that list of the books, while not necessarily exhaustive, is quite comprehensive. Practitioner’s journal articles are parsed out from the search effort as described above. The number of peer-reviewed journal articles is 386.

It is worth mentioning that in the search we found that Six Sigma has made its way into textbooks of quality management. Some textbooks actually devoted a significant portion of space to address Six Sigma in details. One excellent example is the text *Managing for Quality and Performance Excellence* (Evans and Lindsay, 2008). We also included these textbooks in the review.

## **4. The Overall Impression of the Current Literature**

### **4.1. The practitioner’s literature**

The practitioner’s literature on Six Sigma is characterized by its massive amount and high redundancy. The high redundancy reflects the main purpose of the practitioner’s literature: education and knowledge dissemination. This very nature actually makes our review effort easy since we only need to review a portion to learn the whole. For books, we reviewed the most popular ones. Then we examined the abstract or the table of contents of a book to determine if a thorough review is needed. We followed the same protocol in reviewing the articles. The high redundancy nature suggests that we are unlikely to have missed important insights.

Books on Six Sigma can be roughly classified into two main types: Six Sigma education and Six Sigma technical guides. The first type focused on introducing Six



Sigma to the general public. These books promote Six Sigma by citing examples from successful companies, particularly GE. The second type emerged and boomed as Six Sigma gained popularity. To date, they have completely outnumbered the first type. Their focus is tools and techniques used in Six Sigma. These books have fairly consistent and standard content but differ merely in examples or the way materials are presented. It is safe to say they are “Six Sigma textbooks.”

The practitioner’s articles usually appear in the form of case studies. Like books, earlier articles focused on GE and other successful companies (e.g., Delsanter, 1992; Hahn et al., 2000; Kim and James, 2000). Later, many reported the application of Six Sigma in dramatically different contexts, for example, education (Amitava, 2004), food manufacturing (Graeme et al., 2004), emergency rooms (Maniago et al., 2005), and infection control (Vote and Huston, 2005). These articles address various issues related to Six Sigma. Such issues include but are not limited to Six Sigma roles and responsibilities (Hoerl et al., 2001), project selection (Snee, 2001; Snee and Rodebaugh Jr, 2002), and organizational culture change (Arthur, 2005).

It seems that Six Sigma was particularly welcomed by the healthcare industries. A large portion of the practitioner’s articles address healthcare related issues. The healthcare industries have traditionally emphasized the importance of quality excellence. It is not a big surprise that they have followed the tradition to actively adopt Six Sigma.

#### **4.2. The academic literature**

We first present some descriptive statistics about the academic literature. Table 1 lists all papers by their published year. Table 2 lists all papers by journals.

Table 1: Articles by published year

<b>Year</b>	<b>Number of articles</b>
2008 (including articles in press)	37
2007	23
2006	26
2005	17
2004	22
2003	10
2002	9
2001	3
2000	3
Prior to 2000	4

Table 2: Articles by Journals

<b>Journal Name</b>	<b>Articles</b>
Management Science	1
Journal of Operations Management	4
Manufacturing and Service Operations Management	1
International Journal of Operations & Production Management	2
International Journal of Production Research	7
International Journal of Production Economics	2
Production and Inventory Management Journal	2
European Journal of Operational Research	1
Operations Management Research	2
The Quality Management Journal	8
Total Quality Management & Business Excellence	25
The TQM magazine	37
Interfaces	1
The Journal of the Operational Research Society	2
International Journal of Productivity and Performance Management	3
Quality Engineering	9
Journal of Quality in Maintenance Engineering	2
The International Journal of Quality & Reliability Management	10
International Journal of Manufacturing Technology and Management	1
Journal of Manufacturing Technology Management	4
International Journal of Services Technology and Management	2
Managing Service Quality	4
International Journal of Product Development	5
Journal of Healthcare Management	6
Journal of Organizational Change Management	1
Business Process Management Journal	2

Benchmarking	2
The Journal of High Technology Management Research	1
Journal of Air Transport Management	1
Robotics and Computer-Integrated Manufacturing	1
Technovation	1
Journal of Materials Processing Technology	2
Expert Systems with Applications	2
Applied Soft Computing	1

Three observations can be made from the two tables. First, the number of research articles on Six Sigma has grown substantially since the 2000s. This should not be surprising because the management fad concern was gradually alleviated over time, and consequently, research interest in Six Sigma increased substantially (Goh, 2002). We also expect the interest continue to grow based on the fact that more and more papers were submitted to top academic conferences. Second, only a small portion of the articles have appeared in top business research journals. Five articles specifically addressing Six Sigma (Choo et al., 2007a; Linderman et al., 2006; Linderman et al., 2003; Schroeder et al., 2008; Zu et al., 2008) have appeared on the Journal of Operations Management, and one article (Choo et al., 2007b) appeared in Management Science. In contrast, the bulk part of the literature is still from lower level journals. In fact, most articles are from two journals that are highly practitioner oriented: Total Quality Management & Business Excellence, and The TQM magazine. Third, we observed a shift of research focus over time. Earlier research on Six Sigma focused on technical issues. The most recent studies addressed much broader managerial issues related to Six Sigma.

## **5. Definition of Six Sigma**

Definition of Six Sigma is the very first and a fundamental issue addressed by the literature. The importance of a precise definition to rigorous research can never be

overstated (Wacker, 2004). What is surprising, however, is that even after two and half decades in practice, a commonly agreed definition of Six Sigma is yet to be developed (Schroeder et al., 2008). To different people, Six Sigma means different things (Jiju, 2004). Our review shows that different definitions can be categorized into four types.

## **5.1. Six Sigma as a defect rate metric**

### *5.1.1. Definition*

The very first definition of Six Sigma is that it is a defect rate metric, specifically, it means 3.4 DPMO. This is actually the origin of the name Six Sigma. Statisticians have used the Greek letter Sigma to refer to standard deviation. Six Sigma is simply six standard deviations. What it truly means is that a process is highly capable that customer specifications are actually six standard deviations away from the process center (see Figure 1). Since a product will only be considered defective if it is produced outside of customer specifications, a process with such a high capability will almost produce no defect.

The mathematical calculation of 3.4 DPMO is based on two assumptions: the process output follows a normal distribution, and the process mean may shift up to 1.5 standard deviations in the long term. In the extreme situations when the process mean has shifted 1.5 standard deviations one way or the other, the most number of defects the process will produce can be calculated as  $P(Z > 4.5) + P(Z > 7.5)$  (Bothe, 2002). Since  $P(Z > 7.5)$  is virtually zero, Six Sigma is technically  $P(Z > 4.5)$ , which is 3.4 per million (see Figure 2).

Figure 1: Six Sigma as a defect rate metric.

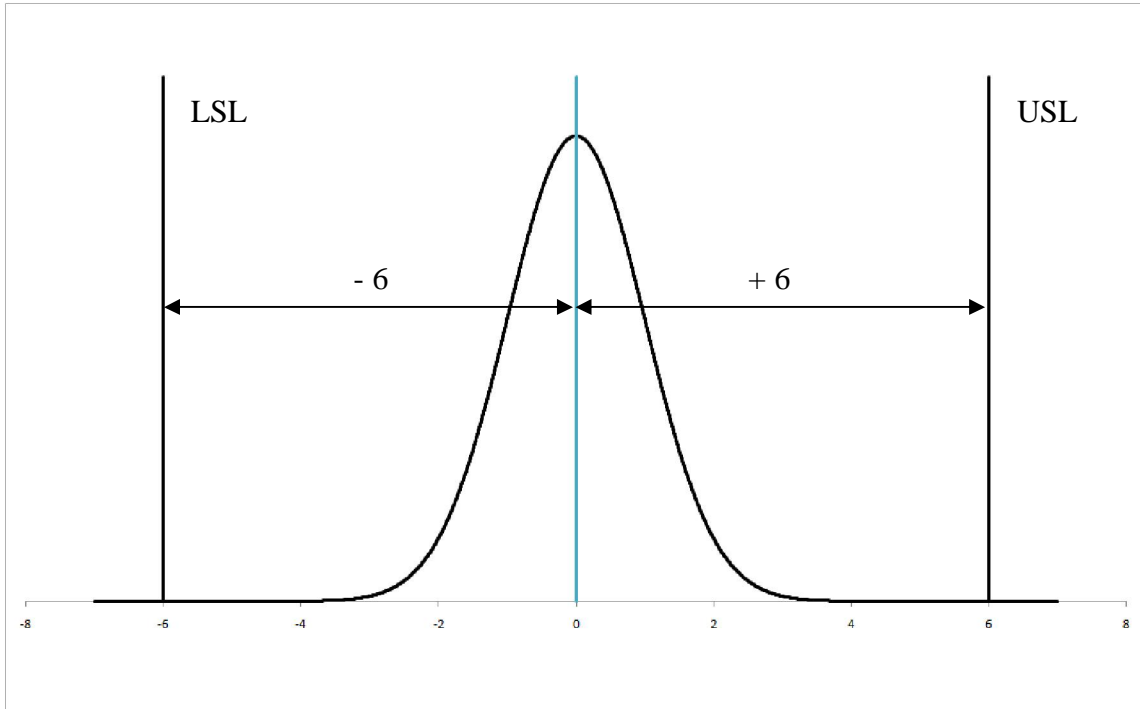
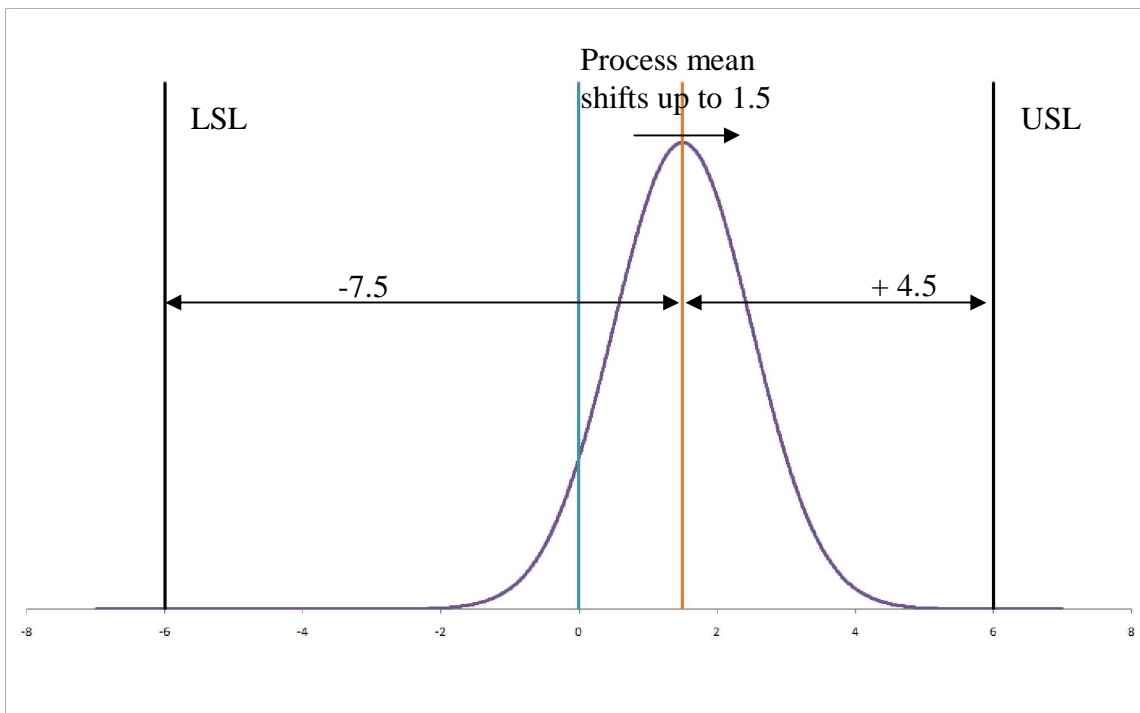


Figure 2: Calculating DPMO for Six Sigma (the process mean shifts up to 1.5 standard deviations in the long term).



The concept of process Sigma level is closely related to Six Sigma and is just the reversed side of the definition. If a process produces a certain number of DPMO, what is the number of Sigma of the process, i.e., process Sigma level then? The calculation is the same as described above but reversed. For example, a process producing 1300 DPMO is a 4.5 Sigma level process. To simplify the matter for practicing managers, consultants have constructed a table showing the translation between defect rate and Sigma level. It is easy to see that a process's Sigma level actually reflects a process' capability. The higher the Sigma level, the higher the process capability.

While still being debated, Six Sigma is strongly supported by the theoretical notion of zero defect. According to Crosby (1979), defects cause waste, rework, or scrap, and eventually lead to customer dissatisfaction. If a process can achieve Six Sigma quality level, it will literally produce no defective product. This will not only reduce waste and cost but also improve customer satisfaction.

The above discussion clearly shows that Six Sigma is closely related to statistical process control and the term itself does not convey any new insight. So why did Motorola engineers create these new terms in the first place? Our review seems to suggest two main reasons. The first one is the motivation to avoid resistance of statistics from ordinary employees. It is generally accepted that ordinary American employees do not like statistics and consider it a boring subject. Since most of the quality improvement tools and techniques are intimately related to statistics, it makes sense to create terms that can make matter simpler for easier acceptance. The second reason is the need to establish a common language across industries. Processes from different industries can be vastly different, yet they can be measured on their sigma level or whether they have achieved

Six Sigma level quality. This enables easy cross-industry learning. In the practitioner's literature, it is actually one important selling point for Six Sigma that a bank can learn from a healthcare organization if the latter's process has a higher process Sigma level, regardless of the dramatic difference between the two organizations.

#### *5.1.2. DPMO versus DPMU*

One issue worth noting is the letter "O" in the acronym DPMO. The letter "O" refers to "opportunities." According to Six Sigma consultants, a process may have multiple "opportunities" to make a defect. Hence the calculation of DPMO takes the number of opportunities into consideration. This means DPMO is not the same as defects per million units (DPMU). DPMO is always lower than DPMU because the number of opportunities is included in the denominator.

Using DPMO has some interesting implications. To calculate DPMO, process owners or operators must first identify opportunities that lead to defects. This is actually a necessary and essential step toward process improvement. In contrast, DPMU is only concerned with the final output. DPMO also makes it "easier" to achieve Six Sigma level quality. The more opportunities identified, the easier to obtain a low DPMO. A complicated process with sizeable defect rate can still achieve Six Sigma quality level because of the large number of opportunities identified. This makes Six Sigma more attractive to service industries because Six Sigma is no longer an unattainable goal. Service processes tend to involve more customer interactions and have more opportunities to produce defects than manufacturing processes. The process Sigma level of service processes is usually within the range of 1.5 to 3 (Pande et al., 2000), if calculated based on DPMU. However, if DPMO is used instead, many service processes

can actually achieve Six Sigma quality level simply because of the large number of opportunities identified.

While a clever marketing trick to sell Six Sigma to service firms, the use of DPMO could be problematic because the term “opportunity” has never been carefully defined. The use of DPMO makes it possible to “improve” a process’ Sigma level by identifying more “opportunities” instead of true improvement effort (de Treville et al., 2008). In the extreme case, a complicated process will be considered a Six Sigma level process yet still produces many defective products. Such fraudulent practices will contaminate the high quality image associated with Six Sigma. It is also possible to lead to complacency since processes can easily achieve Six Sigma level quality. This will defeat the purpose of Six Sigma which is about achieving high quality.

### *5.1.3. Critiques*

Overall, Six Sigma as a defect rate metric (i.e., 3.4 DPMO) is considered a high quality standard. However, this definition is subject to challenges on two aspects. First, the definition of high quality is dependent on the business context. For example, Six Sigma is still a low quality standard for some industries (e.g., passenger safety standard in the airline industry) while it is too high a standard for others. Second, the use of DPMO instead of DPMU makes it easier for service processes to achieve Six Sigma, but it will not be helpful to maintain Six Sigma’s high quality image.

The other issue is that DPMO may have promoted Six Sigma at the expense of statistical rigor. The calculation of DPMO for a process is based on two implicit assumptions. First, the probability distribution for any “opportunity” to cause a defect is assumed to be normal. Second, all “opportunities” are assumed to be independent from each other. Obviously, statistical rigor is compromised if these assumptions are not met.



In other words, DPMO may contribute to the misuse of statistics (de Treville et al., 2008). The implication is not yet clear but it could be an interesting research question to explore.

## **5.2. Six Sigma as a set of tools and techniques, or an improvement method**

A more common definition of Six Sigma is that it is a set of tools and techniques for problem solving or process improvement (e.g., Das et al., 2008). Some define Six Sigma as an improvement method that holds the set of tools and techniques together. This definition reflects the evolution of Six Sigma over time. While viewing Six Sigma as a defect rate metric is free of dispute, Six Sigma today means much more than a metric. Over time, many tools and techniques have been developed to help firms improve their processes to achieve Six Sigma level quality. The use of these tools and techniques is guided by an overarching structured improvement method known as DMAIC (Define, Measure, Analyze, Improve, and Control). In fact, DMAIC is so well known that many consider it a synonym to Six Sigma.

DMAIC is a structured problem solving method. It has five stages with each letter in the acronym stands for one. A problem must be first clearly Defined, usually in the form of defects produced by a process. Then the Metrics for the problem are established. In the Analysis phase, data is collected to explore the root causes of the problem. Improvement solutions can then be developed to address the root causes. Finally, the effectiveness of solutions are Controlled after the implementation. Different tools and techniques are used in each stage. The DMAIC method emphasizes data analysis and fact-based decision making. The method guides a structured exploration of reasons leading to the problem. The essence of the DMAIC method is to reduce variation in a process to achieve high conformance quality in customers' terms.

While some argued that DMAIC method is a new method, it is easy to recognize that it is a revised version of well-known problem solving methods such as Plan-Do-Check-Action (PDCA) and Plan-Do-Study-Action (PDSA). Both PDCA (Shewhart, 1931, 1939) and PDSA (Deming, 2000) emphasize a structured method toward problem solving and use similar tools and techniques. The only difference is probably the addition of the Control phase in DMAIC. However, one can easily argue that the application of PDCA or PDSA is never a single cycle matter, the iteration of multiple cycles means an implicit control phase must be in place.

The tools and techniques used in Six Sigma are also not unique to Six Sigma. Most tools and techniques are identical to those found in a classic TQM program. Others are generic problem solving tools and techniques. It is more about a convention to call the set of tools and techniques Six Sigma. It is probably a marketing effort used by consultants to promote Six Sigma.

### **5.3. Six Sigma as an improvement approach or an improvement program**

A more comprehensive definition of Six Sigma is that it is an improvement approach or an improvement program. While DMAIC is at the core of Six Sigma, equating Six Sigma to DMAIC is too narrow a definition. Such a definition ignores the human resources practices developed for Six Sigma such as Black Belt and Green Belt. The other important aspects such as project selection and project benefits tracking are also not considered in such a definition. A precise definition of Six Sigma needs to consider all these aspects.

A good definition of Six Sigma is given recently by Schroeder et al. (2008, p. 540): *Six Sigma is an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance*

*metrics with the aim of achieving strategic objectives.* This definition captures several distinctive characteristics of Six Sigma: an organizational approach, statistical tools and techniques for variation reduction, a structured method, and metrics orientation, although it leaves out the aspects of customer orientation and project-based implementation (Zhang and Xu, 2008).

#### **5.4. Six Sigma as an improvement philosophy**

Our review also found that Six Sigma has been defined as an improvement philosophy, particularly by GE. GE claims that Six Sigma is its business strategy, corporate culture, company DNA and value, and “the way we live” (GE, 2002). Some Six Sigma advocates also hold the same view. Regardless of the terms used, the essence is to define Six Sigma as an improvement philosophy. Defining Six Sigma as an improvement philosophy is very inspiring and it could lead to major cultural change and performance improvement in an organization.

While inspiring, the Six Sigma philosophy can hardly be differentiated from the philosophy of continuous improvement or pursuing performance excellence. Researchers who define Six Sigma as an improvement philosophy will face serious challenges in establishing discriminant validity. To date, none of the research papers appeared in topic journals defined Six Sigma this way.

#### **5.5. The newness in Six Sigma**

The above discussion shows that an improvement approach or improvement program is the most comprehensive and meaningful way to define Six Sigma. Such a definition takes the evolution of Six Sigma into consideration and reflects the current practices of Six Sigma, thus laying a solid foundation for meaningful managerial research on Six Sigma.

Since the ultimate goal of scientific research is to advance human knowledge, for research on Six Sigma to make substantial progress, an important question has to be answered first: What is new in Six Sigma? This is a highly relevant question since some still view Six Sigma as a re-labeled TQM program (e.g., Beer, 2003; McManus, 1999), hence not really new. Comparisons between Six Sigma and TQM have been done by both practitioners (Pande et al., 2000) and researchers (Schroeder et al., 2008; Zhang and Xu, 2008). These comparisons suggest that Six Sigma represents a new approach to quality management and is usually implemented as an improvement program. The distinctive elements of Six Sigma are summarized in Table 3 below.

Table 3: Distinctive elements of Six Sigma

Elements	Descriptions
Customer orientation	Customer orientation is an important principle of quality management. Deming (2000) and other quality gurus have consistently emphasized the importance of understanding customer requirements. What is new is the unprecedented emphasis and support put in place for this old principle. At the project level, each Six Sigma project is required to clearly demonstrate its value to customers. And the benefits of the project must be clearly visible from customers' perspective. At the organization level, customer orientation is used as a principle to select and prioritize projects by the project selection committee (Eckes, 2000; Harry and Schroeder, 2000; Pande et al., 2000).
Leadership engagement	It is not a surprise that the success of quality management effort requires strong top management support. What is new in Six Sigma is the systematic mechanism put in place to ensure that leadership team is engaged and Six Sigma stays on the organization's dashboard. In Six Sigma, senior executives act as champions and they are directly involved in projects. This ensures right projects are selected and receive buy-in from the organization. Black Belts (full-time improvement project leaders) are selected not only because of their technical knowledge but also their leadership skills (Schroeder et al., 2008).
Dedicated improvement organization	Six Sigma differs from traditional TQM programs in that it requires organization to use Black Belts and set up a dedicated organizational structure for improvement, i.e., what Schroeder et al. (2008) called the "parallel-meso." The structure includes roles such as Green Belt, Black Belt, Master Black Belt, and Champions. It is a convention in Six Sigma to only select an organization's best employees to fill the Black Belt positions (Eckes, 2000; Harry and Schroeder, 2000; Pande et al., 2000). This dedication leads to effective improvement and

also makes the effort easy to measure.

Structured method	In comparison to past quality programs, Six Sigma is highly prescriptive in demanding that each project must strictly follow the DMAIC structured method. The method supports structured exploration of root causes and structured control of the process to produce desired output. The emphasis of adhering to a standard method helps create a common language across the whole organization, which benefits knowledge creation and dissemination (Choo et al., 2007a, b).
Metric focus	Six Sigma emphasizes metrics in either customers' or financial terms. It also emphasizes rigorous tracking of the metrics to ensure benefits are obtained from improvement projects. All Six Sigma projects must have clearly defined goals, expressed in metrics such as Critical-to-Quality (Linderman et al., 2003). Each project is carefully audited on its intended and realized benefits, usually in financial terms and certified by the organization's finance department or even the chief financial officer (Eckes, 2000; Pande et al., 2000; Schroeder et al., 2008).

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## **6. Six Sigma Research Issues**

Based on a solid understanding gained in the literature review, we next performed a critical analysis of Six Sigma. We have identified the following research issues that might lead to fruitful insights.

### **6.1. Theoretical foundation of Six Sigma**

The first research issue we identified is the theoretical foundation of Six Sigma. Six Sigma has been in practice for a long time but effort to articulate its theoretical foundation just started recently (Schroeder et al., 2008). And it is still debated whether Six Sigma encompasses new theoretical insights (de Treville et al., 2008). This situation is somewhat similar to the Deming management method three decades ago. Deming promoted his 14 points to companies and successfully helped many companies improve performance. However, the underlying theory of Deming's 14 points was not articulated until one decade later (Anderson et al., 1994). A theory articulating how and why Six Sigma can successfully help improve performance is needed for research on Six Sigma to progress further.

## **6.2. Six Sigma and performance improvement**

Empirically validating the effectiveness of Six Sigma is of critical importance. Without scientific evidences supporting its effectiveness, virtually all discussions about Six Sigma become meaningless and irrelevant. After all, Six Sigma is a management intervention, the ultimate test is whether it can lead to better performance (White and Hamermesh, 1981).

Large scale empirical testing of Six Sigma's performance implications is needed. Six Sigma's effectiveness of performance improvement has been supported by richly available anecdotal evidences but only anecdotal evidences are insufficient. We need large scale empirical studies similar to what have been done for TQM programs (e.g., Hendricks and Singhal, 1997, 2001; Kaynak, 2003). There has been some attempt to address the question (e.g., Foster, 2007; Goh et al., 2003). The recent effort of defining and measuring Six Sigma (Linderman et al., 2006; Linderman et al., 2003; Schroeder et al., 2008; Zu et al., 2008) has laid a solid foundation for large scale empirical studies.

Empirical studies should also be conducted at different dimensions and different levels. For example, the performance implications of Six Sigma can be examined from different dimensions: quality performance, operating performance, competitive performance, or financial performance. Performance implications can also be examined on different time horizon: short term versus long term. It is also possible to look at Six Sigma's performance implications on different levels of organizations: project, plant, division, or corporate. We expect these questions to be addressed by future studies.

## **6.3. Six Sigma customization**

Six Sigma's success at GE significantly increased its fame and promoted it to many different types of organizations. The rationale is that processes are actually very similar,

despite the vast difference among organizations. By improving processes, organizations can expect better performance. Anecdotal evidences are very supportive about Six Sigma's effectiveness.

An important question arises as Six Sigma diffuses to different types of organizations. That is, how should different organizations implement Six Sigma? These organizations could be drastically different than the typical manufacturing plants where Six Sigma prospered. Some studies have provided interesting insights (e.g., Gijo and Tummala, 2005; Jiju et al., 2005).

We see an interesting tension between the practices in reality and management theories. In practices, Six Sigma consultants have actively promoted several highly prescriptive rules. The essence is that organizations should strictly follow GE's standard practices. Some consultants even asserted that a main reason for failure is deviation from GE's standard practices. Such a "one size fits all" approach clearly contradicts the long established contingency perspective (Van de Ven and Drazin, 1985). The contingency perspective states that any management intervention has to fit into an organization's specific context to be successful. For Six Sigma, fit means customization of the program. Apparently, practices and theories do not agree with each other on this important aspect.

Probably one way to resolve the tension is to clearly define the defining and discretionary elements of Six Sigma. Defining elements are those that should not be altered at different organizations and discretionary elements should be customized to fit a Six Sigma program into an organization. The contingency perspective provides an overarching framework to understand these complicated relationships. However, the specifics remain unclear. For example, what those elements are? What organizational

contextual factors are important? How do they affect the customization decisions? Answering these questions not only contribute to the management literature but also can provide useful guidance for practicing managers. We expect both qualitative and quantitative studies to explore these questions.

#### **6.4. Six Sigma and organization science**

The unique parallel-meso organization structure in Six Sigma provides an interesting context for research from the organization science perspective. We found two issues particular interesting. The first one is whether a dedicated organizational structure makes improvement effort more effective. The second one is the tension between a rather mechanistic approach and a more adaptive organization.

##### *6.4.1. The parallel-meso structure*

Parallel-meso is a term used by Schroeder et al. (2008) to refer to the organizational structure that is set up within the same organization. This organizational structure is composed of roles including Green Belt, Black Belt, Master Black Belt, and Champions, and is dedicated to improvement. The practitioner's literature highly praised this parallel structure and claimed that this dedication is key to Six Sigma's effectiveness (e.g., Breyfogle et al., 2001; Harry and Schroeder, 2000; Pande et al., 2000).

The establishment of a parallel-meso structure in Six Sigma seems to be in alignment with Juran's (1989) quality trilogy. Juran argued that there are three pillars to quality management: control, improvement, and breakthrough. He did not address organization design issues related to the three though. It seems that Six Sigma advocates establishing a separate organizational unit dedicated to improvement. A separate organizational unit increases accountability and measurability. The separate yet parallel structure maintains the connection to the original operational unit. So the improvement



effort is likely to be considered “ours” instead of “theirs”, which reduces resistance to change. In short, the parallel-meso structure seems to be a new and effective way to implement change programs such as Six Sigma. However, an in-depth theoretical understanding of this new structure is yet to be developed and empirically tested.

The parallel-meso structure means an organization needs to perform at least two tasks simultaneously: operation and improvement. This raises several interesting questions. The two tasks are likely to compete for resources. How should organizations manage the potential resource conflict? How should organizations coordinate and balance the demand for resources? What priority should organizations assign to each task? Answers to these questions will contribute to our understanding of this new type of organization.

#### *6.4.2. Mechanistic approach for dynamic environment*

Six Sigma’s rather mechanistic approach to improvement also brings up an interesting tension. Six Sigma is highly prescriptive in mandating how improvement effort should be implemented. However, will such a mechanistic approach be appropriate for organizations operating in a dynamic environment? Organization scientists have clearly indicated that a mechanistic organization is suitable for highly repetitive tasks where the efficiency is high but the ability to adapt to change is weak. In contrast, an adaptive organization is suitable for dynamic environment. Such an organization sacrifices efficiency to a certain degree to gain high flexibility to adapt to changes. The organizational structure for the two types of organizations are drastically different (Lawrence and Lorsch, 1967; Scott, 2001). The contemporary business environment is most appropriately characterized by versatile customer requirement, complex global supply chains, and fierce global competition. Therefore, organizations need to be

adaptive. It is thus an interesting question whether Six Sigma, a mechanistic improvement approach, can help organizations be more adaptive. Similar questions have been examined by operations management scholars (Collins et al., 1998; da Silveira, 2006). In the case of Six Sigma, although anecdotal evidences are richly available, the theoretical understanding of the issue remains primitive and the implications are not entirely clear.

### **6.5. Six Sigma and human resources management**

One distinctive feature of Six Sigma is the use of several unique human resources practices, particularly the use of full-time improvement specialists, i.e., Black Belt. These human resources practices are generally believed to contribute to Six Sigma's success for the reasons discussed earlier. At the same time they also bring in a number of interesting issues: selection of Six Sigma personnel, job design for Six Sigma personnel, training and development, performance appraisal, and compensation.

Six Sigma personnel selection is a crucial decision. The staffing process will directly affect the effectiveness of Six Sigma. Using the important role of Black Belt as an example, consultants have prescribed a simple and inspiring principle: Organizations should select their best employees to become Black Belts. However, this principle is actually highly vague in that the definition of best employee is not always clear. This internal-oriented principle will also make it difficult to hire highly qualified talent externally. Several questions remain unanswered: What should the selective staffing policy be for organizations implementing Six Sigma? How does the selective staffing policy affect Six Sigma's effectiveness? In addition, considering the fact that a Six Sigma program usually will last years, the selective staffing policy also needs to adapt as

organizations entering more advanced stage of Six Sigma but it remains a myth how such adaptations should be.

Job design for Six Sigma personnel is also critically linked to Six Sigma success. Job design should be aligned with an organization's overall strategy. The roles and responsibilities of Green Belt, Black Belt, Master Black Belt, and Champions are mature since Six Sigma has been implemented by many organizations. However, job rotation, and job enrichment and enlargement remain fuzzy. This is a particularly relevant issue when organizations enter a more advanced stage of Six Sigma. Some Six Sigma personnel need to rotate back to functional areas after completing their assignment. Organizations also need to select new Six Sigma personnel. Unfortunately, this re-integration process seems to be largely chaotic at many organizations.

Next, Six Sigma provides an interesting context for the study of training and development, performance appraisal, and compensation issues. Six Sigma requires intensive training and development of employees. Large companies need to spend millions of dollars on training and development. To get certified, a Green Belt typically needs to attend two weeks of training while completing a project within three to six months. A Black Belt needs to attend two additional weeks of training while completing a more complicated project. The training is a combination of both on-job and off-job. The training cost for an individual Green Belt is usually within the range of \$4000 to \$8000. The total training cost is massive at companies such GE where every employee will receive Green Belt training eventually. However, it is surprising that the effectiveness of such a massive scale training program has never been carefully studied.

Similar issue exists for performance appraisal. Six Sigma has a metric focus and orientation that makes the tracking and measuring savings from Six Sigma projects easy. Naturally, the evaluation of Six Sigma projects is biased toward “hard” savings, i.e., cost savings that are clearly measurable. However, this is a rather mechanistic performance evaluation approach. It is not fully compatible with the more comprehensive performance appraisal approaches, for example, 360-degree appraisal. The effect of this incompatibility has not been carefully studied.

Compensation is closely related to performance appraisal. Organizations use compensation policies to reward results as well as encourage desirable behaviors. In Six Sigma, compensation is likely biased toward “hard” dollar savings due to the bias in performance appraisal. This bias has the positive impact of encouraging employees seeking more opportunities to cut waste and reduce cost. However, it can also have the negative impact of pushing employees to avoid risky but highly beneficial projects. This could be detrimental to an organization’s strategic objectives. Research on these issues can certainly provide valuable insights contributing to both the literature and practices.

## **6.6. Six Sigma and innovation**

Innovation has been a key concern for contemporary organizations as they face ever-changing customer requirements. Innovation is a major source for competitive advantage. Firms strive to be innovative. Naturally, one concern is whether the implementation of a Six Sigma program will strengthen or weaken an organization’s innovativeness.

The extant literature seems to suggest that Six Sigma may hinder an organization’s effort to be innovative. Six Sigma has a deep connection with process management. The premise of Six Sigma is that improving an organization’s processes can lead to consistent

output that is welcomed by customers. By reducing variations, Six Sigma makes processes more stable and consistent. But variation reduction effort may be incompatible with exploration activities, which are variation creation in nature. Benner and Tushman (2002, 2003) proposed a theoretical model explaining why process management will impede innovation and empirically tested the relationship in the paint industry. They found that firms good at process management have a tendency to focus on exploitation. Exploitation refers to using knowledge learned in one place to replicate the success at other places. Exploitation has relatively low risk and can usually lead to clearly visible results. In contrast, exploration requires experimentation and is highly risky in nature (March, 1991). As a result, exploitation tends to drive out exploration. Over time, organizations become less innovative, as shown by the number of patents filed. Since Six Sigma has a deep root in process management, it is likely Six Sigma will lead organizations to be less innovative.

Several counter arguments can be made against the above assertion. The Benner and Tushman (2002) study only looked at product innovation but did not include the other type of innovation: process innovation. Their study also did not look at the nature of the innovation, which can be incremental or radical. The number of patent filed is a proxy but not a direct measure of innovation. The number of patent filed is not necessarily the same as the quality of innovation. In Six Sigma, both exploitation and exploration are included: a recent study suggested that Six Sigma has both structural control versus structural exploration (Schroeder et al., 2008). In their view, Six Sigma has a controlling mechanism to ensure proper execution but it also encourages employees to explore outside the normal boundary. New knowledge is created and disseminated in

this process (Choo et al., 2007a, b). In other words, Six Sigma will promote instead of stifle innovation.

In summary, Six Sigma may have provided an interesting context for the study of organizational ambidexterity. An ambidextrous organization successfully balances the two types of organization learning and is better suited for changing environment (Tushman and O'Reilly, 1996). The positive impact of organizational ambidexterity received strong empirical support (e.g., He and Wong, 2004). However, the mechanism for maintaining this delicate balance is not all that clear. Six Sigma has both structural control and structural exploration that must be balanced to be successful. We can expect fruitful insights on the issues discussed from the study of Six Sigma.

### **6.7. Six Sigma and Leadership Development**

Leadership is undoubtedly the single most important factor for the success of any change initiative. Leadership is the first category in the Baldrige framework (NIST, 2007) and also has the highest weight of any category. Visionary Leadership is the foremost concept in the Deming management theory (Anderson et al., 1994). Various studies have consistently shown that top management support, leadership, or some other terms representing the same concept is usually the driver of quality management program success (e.g., Flynn et al., 1994; Kaynak, 2003; Powell, 1995). Six Sigma is not an exception (Schroeder et al., 2008).

What is interesting is the leadership development component seen in some Six Sigma programs. First of all, Six Sigma emphasizes that it must engage an organization's top leaders and it stays on the leaders' agenda all the time. However, many times Six Sigma requires even more in that it mandates all managers be familiar with its method and language. GE does this by clearly stating that a manager will not be promoted unless

the manager receives a Green Belt certificate (Henderson and Evans, 2000; Pande et al., 2000). In other words, Six Sigma has a strong leadership development component.

Leadership development differs from leadership in that it considers the dynamics of leadership. Leadership development is about expanding the collective capacity of organizational members to engage effectively in leadership roles and processes (Day, 2001; McCauley et al., 1998). Leadership development practices include 360-degree feedback, coaching, mentoring, networks, job assignment, and action learning (Day, 2001). The result is that the whole organization, not just top leaders, is engaged in the leadership process. With leadership development practices in place, leadership is no longer a static and exogenous factor to quality improvement programs. It is actually an outcome of the improvement program, which in turn enhances the program. In short, leadership development constructs a positive loop that is likely to lead to sustained improvement program success.

The above discussion implies a positive relationship between leadership development and improvement program success. In fact, some Six Sigma practitioners have asserted that leadership development is the hidden secret of Six Sigma success. This is a highly inspiring statement. However, the underlying theoretical model is yet to be articulated. Research effort is needed to uncover the model and its associated theoretical concepts. Empirical studies can then validate the role of leadership development in the success of Six Sigma, or any other major improvement programs.

## **6.8. Six Sigma and Project Management**

Project-based implementation is a distinctive characteristic of Six Sigma. Six Sigma improvement effort is organized by projects. Organizations look at improvement

ideas and select some to be implemented. Project is the vehicle of improvement in Six Sigma.

Obviously, the selection of improvement projects is of critical importance. Researchers have proposed concepts such as strategic project selection (Schroeder et al., 2008; Zhang et al., 2008). Strategic project selection describes how organizations select and prioritize improvement projects. The selection and prioritization effort ensures that all projects selected form a program, i.e., a set of projects that serve a common strategic objective (Project Management Institute Standards Committee, 2004). Strategic project selection has significant implications that affect the whole organization. It is indeed the central controlling mechanism of Six Sigma. It effectively determines resource allocation and reveals the priority of the whole program. It is through strategic project selection that a balance between exploitation and exploration can be achieved.

To make sound strategic project selection decisions, organizations need both systematic methods and a solid understanding of relevant factors. Several project selection methods have been proposed. For example, Yang and Hsieh (in press) suggested using the national quality award criteria for Six Sigma project selection. However, the effectiveness of these methods is yet to be examined. Meanwhile, some studies have looked at factors that affect strategic project selection. Zhang et al. (2008) found that project management infrastructure in an organization affects the organization's strategic project selection. In other words, a fact-based and disciplined organizational culture lays a solid foundation for strategic project management. We expect to see more studies contribute to a more in-depth understanding of the issue.



Six Sigma and project management are intimately linked. Studying Six Sigma potentially can make significant contributions to the project management practices and literature. For example, two recent studies have shown that goal setting and management is critically related to Six Sigma project success (Linderman et al., 2006; Linderman et al., 2003). Others have looked at the DMAIC method that is widely used to manage Six Sigma improvement projects (Kwak and Anbari, 2006). Zhang and Xu (2008) explored whether DMAIC can be used to manage information systems projects. We expect to see more studies looking into Six Sigma project management.

### **6.9. Six Sigma in the supply chain**

As a process improvement program, Six Sigma naturally is not limited by organizational boundaries. It should be implemented in the supply chain for maximum benefits. Leading companies have expanded their Six Sigma programs to supplies and customers (e.g., 3M, 2003; GE, 2002). But this effort can hardly be considered systematic. In short, the linkage between Six Sigma and supply chain management is weak at best.

The lack of research leads to many unanswered questions. Is Six Sigma an effective way to improve supply chain quality and performance? How should firms expand their Six Sigma programs to suppliers and customers? Is Six Sigma an effective means for supplier development? Does implementation of Six Sigma affect buyer-supplier relationship? Is the success of Six Sigma in the supply chain dependent upon the buyer-supplier relationship? What are the factors that affect Six Sigma implementation in the supply chain setting? Answering these questions can provide valuable insights for both practicing managers and scholars.

## **6.10. Design for Six Sigma**

Finally, Design for Six Sigma (DFSS) is an important component of Six Sigma. DFSS focuses on developing products that are highly reliable and manufacturable. Not much has been studied about DFSS. The extant ones are mostly engineering or statistical studies. The managerial implications of DFSS largely remain unclear to business scholars. After all, we have yet to see a study that shows whether DFSS leads to better design performance.

## **7. Conclusion**

Six Sigma has been widely adopted by different types of organizations for a long time period but research on it is still in its early stage. Researchers are generally concerned that it is a management fad. This is a legitimate concern but it apparently hindered scientific research effort on Six Sigma. Over time, anecdotal evidences suggest that Six Sigma is very likely an effective means to improve performance. The proven track record of Six Sigma at many different contexts has alleviated researchers' concern and boosted research interest, as manifested by the number of published articles on Six Sigma recently.

To gain an in-depth understanding about Six Sigma, we performed a comprehensive search of the literature. We found that the bulk part of the literature on Six Sigma is practitioner oriented, including about 700 book titles. Academic research on Six Sigma has produced 154 papers, among them about 10 papers appeared on top business research journals. The majority of the academic articles were published in the past several years. This is in line with the observation that research interest on Six Sigma has grown substantially yet still in its early stage.

We first studied the definition of Six Sigma. A proper definition is a fundamental step toward rigorous research insights. Our review revealed that Six Sigma has been defined very differently. It means different things to different people. We found that these definitions can be classified into four types: a defect metric, a set of improvement tools or an improvement method, an improvement approach or an improvement program, and an improvement philosophy. We analyzed each type to identify the strength and weakness. Our comparison analysis showed that Six Sigma represents a new approach to quality management and process improvement, and it is often implemented as an improvement program. Based on the analysis of the literature, we summarized the defining elements of Six Sigma. Six Sigma emphasizes customer orientation, rigorous tracking of project benefits, and a common improvement method for variation reduction. A Six Sigma program is supported by strong leadership support and several unique human resources practices. Six Sigma thus represents an interesting research subject itself as well as a research context.

In light of the management literature, we then performed a critical analysis of Six Sigma to identify interesting research issues. We identified ten research areas. We first suggested empirical studies on the effectiveness of Six Sigma. Clearly, performance improvement effectiveness is an ultimate test to establish the validity of any management intervention (White and Hamermesh, 1981). We then suggested studies on how Six Sigma programs should be customized to fit different contexts. Many believed that all organizations should follow GE's way to implement Six Sigma. But this is clearly against the well-established contingency perspective. Next we suggested studying Six Sigma from the organizational science perspective. Six Sigma uses a rather mechanistic

approach to improvement, yet the theories suggest that an adaptive approach is more effective for dynamic environment. Studying this tension might lead to interesting novel insights.

We also suggested that Six Sigma can be studied from other perspective. One perspective is about the relationship between Six Sigma and innovation. Six Sigma emphasizes improvement, which is an exploitative activity. Scholars are concerned that a focus on exploitation will stifle exploration, which eventually lead to the demise of innovation inside an organization (Benner and Tushman, 2002, 2003). However, it remains unclear whether the implementation of Six Sigma programs leads firms to be less innovative. Six Sigma thus provides a new context to look at the old tension. In addition, issues such as the relationship between Six Sigma and project management, and Six Sigma and supply chain management may all lead to fruitful research insights.

This study makes several contributions. This study reviewed the extant literature to summarize the current understanding of Six Sigma. Since scientific research always follow a cumulative tradition, it is important to know what has already been studied before new knowledge can be created. This study provided a thorough discussion on the definition of Six Sigma. This effort helped clear many confusions around Six Sigma. This effort also helped lay a foundation for future research since a clear definition is a fundamental first step. Lastly, we suggested research questions that could lead to the discovery of important new insights.

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To study Six Sigma is to prime yourself for a successful and rewarding career. Introduced more than 30 years ago by Motorola, Six Sigma would go on to become the most flexible, versatile and widely-applicable project management framework in the world. At its core, the Six Sigma DMAIC methodology is all about optimising performance and eliminating waste. Across all contemporary sectors, Six Sigma can be applied to almost any process, project or activity in an organisational setting. Business owners and prospective entrepreneurs. Senior personnel and decision-makers. Anyone interested in high-level project management. Jobseekers working on their CVs and employability. (5) Six Sigma is prospective methodology as compared to other quality programs as it focuses on prevention on defects rather than fixing it. (6) It is attentive to the entire business processes and training is integral to the management system where the top down approach ensures that every good thing is capitalized and every bad thing is quickly removed.

Disadvantages. (1) Applicability of Six Sigma is being argued among the Six Sigma critics. They opined that the quality standards should be according to specific task and measuring 3.4 defects per million as standard leads to more time spent. Consequently, Six Sigma provides an interesting context for a number of research questions. We then discussed these prospective research questions. This study laid a foundation for future research on Six Sigma. Keywords: Six Sigma; literature review; future research. Six Sigma: A Retrospective and Prospective Study. 1. Introduction Six Sigma is an important advance in quality management and process improvement in the last two decades. Six Sigma has gained wide popularity in various types of organizations since the 1990s. Most Fortune 500 companies have adopted Six Sigma (Goh, 2002). Six Sigma is a measurement-based strategy for process improvement. It is a methodology, which aims at improving process and increasing customer satisfaction (Both internal & external). The concept behind this approach is to reduce the variation in processes. This reduction leads to consistent and desired outcomes from processes. Hence, Continuous process improvement with low defects is the goal of this method. Six Sigma Model (DMAIC Model) for process quality improvement: Six Sigma follows the DMAIC model for quality improvement and problem reduction (For existing processes). This well-defined Six sigma refers to the methodology and practice of focusing on developing and delivering products/services that perform at high standards. It is a Quality philosophy and a management technique. Six sigma is not a standard or a certification or another metric like percentage. Six Sigma's Approach to Problem Solving. Six Sigma was originally coined by Bill Smith. He was an American engineer and also known as father of Six sigma. It was first implemented in Motorola in the year 1986 as a general approach to measuring quality in business performance terms. Further, it becomes popular management approach at GE with Jack Welch in early 1990s. General Electric reported tangible benefits of \$2.5 billion per year due to Six Sigma initiatives and made it an organization wide strategy.