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Integrating the Many Facets of Six Sigma

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ABSTRACT We seek to provide a unified characterization of Six Sigma by studying the phenomenon from the perspectives of business economics, organizational theory, competitive strategy and industrial statistics, and we pinpoint its core methodological principles. We describe Six Sigma as a prescriptive framework for the routinization of incremental product and process innovation, organized as a decentralized project organization. The methodological basis of Six Sigma consists of principles borrowed from methodology for empirical inquiry, and facilitated by techniques from quality engineering, problem solving and marketing.

KEYWORDS competitive strategy, DMAIC, evolutionary economics, quality improvement, six sigma level

INTRODUCTION

In recent years, Six Sigma has developed into a standard approach for quality improvement in the manufacturing industry, but as well in the service industry and healthcare. The approach was developed by Motorola in the 1980s, but gained enormous momentum after its adoption by General Electric in the mid 1990s. Six Sigma is a methodology for managing and executing quality improvement in projectwise fashion in organizations. Besides a conceptual framework, specifying its purpose and rationale, Six Sigma offers prescriptions for improvement projects. These prescriptions consist of a roadmap (the DMAIC phases, see later), a large number of tools and techniques, and a number of improvement principles. Further, it offers a model for designing an appropriate organizational structure, in which projects are run by green and black belts, and reviewed by champions. Finally, Six Sigma offers guidelines for training, project selection, and implementation planning.

Linderman et al. (2003) remark that "while Six Sigma has made a big impact on industry, the academic community lags behind in understanding of Six Sigma." Brady and Allen (2006) give a recent and thorough overview of publications in the scientific literature devoted to the subject. De Mast et al. (2006) give an account for the practitioner. One of the difficulties studying Six Sigma, is that the phenomenon is so encompassing and has so many facets, that one cannot expect to obtain a complete picture by studying it from the perspective of a single discipline. Although specific elements of Six Sigma can be sensibly analyzed from a more limited angle, obtaining an understanding of the phenomenon as a whole requires

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the integration of at least the viewpoints of business economics, quality engineering, and industrial statistics.

This article aims to give an overview of Six Sigma from a variety of perspectives and disciplines. Given restrictions to the length of this article, the discussions below cannot be in-depth. One of the objectives of the article is to provide references to more thorough accounts and to link aspects of Six Sigma to the relevant scientific literature. But the emphasis will be on placing these various viewpoints alongside in order to be able to characterize the Six Sigma phenomenon as a whole.

Below we position Six Sigma in its historical context, and then discuss the phenomenon from the viewpoints of business economics, organizational theory, competitive strategy, Six Sigma as a method, and from the perspective of statistics. These discussions provide the material for an encompassing characterization of Six Sigma.

HISTORICAL ANGLE

As described elsewhere (Bisgaard and De Mast, 2006), Six Sigma should not be seen as a revolutionary development. A more realistic view is that it is a phase in an ongoing evolution of methods and approaches for quality and efficiency improvement.

The emergence of large international enterprises by the end of the nineteenth century stimulated the development of management as a professional discipline. Following pioneers like Henri Fayol and Frederick Taylor, the twentieth century saw the development and refinement of the knowledge and principles required to manage large organizations. Besides management, also the disciplines of statistics and quality engineering developed from infancy to mature disciplines in the twentieth century. After the second world war, and especially from the late 1970s onward, the Western paradigm of mass fabrication was in many industries superseded by the Japanese system of lean manufacturing. Where volume, economies of scale, and productivity had been the economic focal points in leading industries in the West, the Japanese started experimenting with manufacturing systems focusing on flexibility, speed, and efficiency. For the system to work, one needed processes that run like clockwork: optimized changeovers, aggressive defect reduction, and partnerships with suppliers. Running one's organization like clockwork implied delegation of authority to the shopfloor. The Japanese had discovered that manufacturing virtuosity and quality can be powerful strategic weapons, and many industries saw the emergence of Japanese companies that surpassed their Western competitors on several dimensions simultaneously, such as price, conformance quality, and delivery.

The Japanese success resulted in a flood of quality methods and principles: quality circles, just in time, kanban, kaizen, total quality management, statistical process control, etc. Some of these 'flavors of the month' turned out to be just fads. Others had their merits, but appeared less generic than claimed and failed to endure. Most of the valuable ideas, however, have been integrated in more encompassing approaches, which is probably their right place.

Six Sigma can be seen as the accumulation of principles and practices that were invented in management, quality engineering and industrial statistics in the twentieth century. Many of the techniques and principles that have demonstrated their value can be found in Six Sigma's method. This assimilation of tested and tried ideas continues, with the integration of Lean principles in Six Sigma as one of the most important developments in recent years. New in Six Sigma are the extent of integration of best practices, methodological principles, and techniques in a coherent framework. Earlier comprehensive philosophies and systems have been suggested (total quality management and the Shainin System, to mention just two), but the completeness and comprehensiveness of Six Sigma set it apart from earlier approaches. Equally unequalled is the impact that Six Sigma has on the business world, in manufacturing and beyond, and the scale on which the program is rolled-out in many organizations.

Although Six Sigma can be quite a revolutionary experience for organizations adopting it, the approach itself is a phase in the continual evolution of methodology for quality and efficiency improvement, a development that has been interwoven with the evolution of modern industry. For more elaborate descriptions see Wren (2005) and De Mast and Does (2006).

THE ECONOMIC CONTEXT

Six Sigma is often described as a quality improvement program, but it is difficult to place Six Sigma in economic theories from that perspective. *Quality* is not a concept that is commonly used in economic theories. Further, whether quality improvement covers Six Sigma's intention is an issue that could be debated, but it is certainly a deficient description of its factual use. Many Six Sigma projects pursue the reduction of characteristics such as cycle time, lead time, cost, capital expenditure, et cetera. By stretching the meaning of the word *quality*, such pursuits could be described as quality improvement, as is done frequently in the quality management literature. This attempt to catch many different pursuits under the single concept of quality serves legitimate purposes in some contexts (the economists Wruck and Jensen, 1994, suggest that total quality management and Six Sigma use the rhetoric of quality as an—effective—means to accomplish cultural change). But in the context of making an economic analysis of the benefits of Six Sigma, such conceptual erosion is better avoided. Economists have good reasons to distinguish between product quality, process efficiency, cost, and capital expenditure, and not labeling it all quality.

To link Six Sigma's business rationale to established theories in economics, instead of *quality* we will use the concepts of *innovation* and *routine operations*. A useful framework is Nelson and Winter's evolutionary theory of economic change (Nelson and Winter, 1982). They describe organizations as a collection of routines. Manufacturing processes, sales, back office processes, nursing, marketing: such operations are performed in a repeated manner, which makes it possible and worthwhile to improve them. If one speaks of 'operational excellence,' it is the effectiveness and efficiency of these routines that one refers to, and the routinization of activity in organizations constitutes the most important form of storage of their operational knowledge.

Companies evolve due to changes in the market (competition, demand, and supply), and due to their investment patterns. But beside these factors, Nelson and Winter discern 'search processes' as a driver of change. Search processes are a company's activities for improving its routine operations. Six Sigma is such a search process. This is the role that Six Sigma programs play in organizations: they turn improvement of processes itself into a routine activity. This systematization of process improvement is comparable to the routinization early in the twentieth century of research and development (see Freeman and Soete, 1997).

In the current economy competitiveness is less and less determined by static advantages such as quality and efficiency, and more and more by the rate at which these improve. Continuous improvement, flexibility, and the resilience to adapt to new circumstances and opportunities have become crucial competencies in a highly dynamic and quickly evolving economy. Economists tend to label such pursuits under *innovation*. Innovation plays an important role in economic theories, as it provides a compelling explanation of endogenous growth. Often, the literature distinguishes between breakthrough innovations and incremental innovations. The invention by RCA of the LCD panel is an example of a breakthrough innovation. The subsequent efforts to improve the quality of LCD panels, as well as the efficiency of the processes required to make them, are examples of incremental innovations. These incremental innovations are often not very interesting from a technological point of view, but their cumulative impact on quality and cost is huge (cf Rosenberg, 1982). In addition, innovation is seen by many as the driver of competitive advantage in the 21st century's Western economies. The US Council on Competitiveness (2004), for example, concludes that

> "For the past 25 years, we have optimized our organizations for efficiency and quality. Over the next quarter century, we must optimize our entire society for innovation."

'Routinization of incremental product and process innovation' is a better description of what Six Sigma programs do than 'quality improvement', as it links on to economic theories and current economic realities. Routinized product and process innovation was named *systematic innovation* by Bisgaard and De Mast (2006). Describing Six Sigma as 'systematic innovation' rather than 'quality improvement' places it at the heart of the knowledge economy (Bisgaard, 2006).

SIX SIGMA AND ORGANIZATIONAL THEORY

There are many activities in organizations relating to quality and efficiency (or product and process innovation, for that matter), and they should not all be organized in the same way. Juran (1989) proposed a generally accepted distinction of activities into planning, improvement and control. *Planning* covers the development of new products and processes (including marketing research). This work is typically organized in staff departments. Design for Six Sigma is an approach for planning.

Control consists of the on-line and real time monitoring of production or service delivery, the detection of irregularities, and the reaction to these irregularities. A typical control system entails elements such as a control plan, control points and loops, and inspections. Control is reactive in nature and deals particularly with what Juran calls *sporadic problems*. Its organization should be integrated with the regular (production, back office, service delivery, or other) process, and nowadays its execution is typically the responsibility of the personnel who execute the process. In the Control phase of Six Sigma projects black belts improve the process's control system.

Improvement, finally, is the organized and systematically pursued improvement to increase quality and efficiency to unprecedented levels (Juran calls this *breakthroughs*). Unlike quality control, quality improvement is not an on-line affair, but should be executed in the form of projects, and Six Sigma projects are examples of such improvement projects.

When organizing projects, the first question is: who should run them? Project organizations can be completely centralized (i.e., projects are executed and coordinated by a central staff department), or they can be completely decentralized (projects are executed by line personnel and their coordination is organized in a bottom-up fashion), but a middle course seems more appropriate. Improvement projects should not be run by people who are too remote from the process under study. Central staff, for instance, are likely to have a highly sterile and simplified perception of the problem. Rather the projects should be managed by people who are immersed in its daily detail. The type of knowledge that serves as a basis for improvement projects is called *specific knowledge* by Jensen (1998, ch. 4), one of the leading thinkers in organizational theory. Operators see how their process is running, the peculiarities of incoming material and the typical problems of their machines. Foremen know the particulars of their planning, and salespersons know the idiosyncrasies of customers. This kind of knowledge is, due to its high level of detail, difficult and costly to transfer; staff departments will see only a small and filtered portion of it. Moreover, a lot of know-how that people working with the process have, is what Polanyi (1958) calls *tacit*: unconsciously known, but not easily made explicit. Based on the observation that improvement initiatives are driven by specific and tacit knowledge, economists prescribe that they should be delegated to people who are closely involved in the process or system under study – enter the black and green belts, who are typically selected from the line organization, and dispersed all over the organization.

However, this sort of delegation creates a new problem: the problem of poor integration. People may select projects or improvement actions based on inappropriate criteria, such as their self-interests, the values of their profession, or misconceived ideas of the organization's goals. Economists call this the principal-agent problem, the problem of how to ensure that self-interested decision agents exercise their rights in a way that contributes to the overall organizational objective. A solution is to separate execution from control. Six Sigma tackles this problem by using champions, executive level personnel that supervise the project teams. It is the champions who, seeing the bigger picture of the organization, indicate *what* constitutes strategically valuable improvement goals, and it is the black and green belts, understanding the details of the process, who figure out *how* to improve. Or more precisely: projects are typically *proposed* by people who have context knowledge, but they should be *ratified* by a champion who can assess their merits against the larger corporate objectives. Likewise, projects are *executed* by black and green belts knowing the specifics, but are *monitored* by the champion in the form of regularly scheduled reviews. Project execution is bottom-up, but project coordination is top-down.

The vision of a Six Sigma company is one that invests substantial resources and time in continual product and process improvement (incremental innovation). These activities are decentralized and spread all over the organization. All line departments are responsible for improving their processes. Improvement activities are executed in the form of projects, where initiation and execution come from the line, while projects are coordinated by champions and a Six Sigma Steering Committee, thus ensuring that projects focus on strategically important issues.

SIX SIGMA AND COMPETITIVE STRATEGY

It is often claimed that quality improvement (or more correctly, product and process innovation) brings about profitability and competitive advantage automatically. But closer analysis (De Mast, 2006) learns that the conversion of efficiency and quality improvement into sustainable profitability is all but straightforward. The crucial point is that Six Sigma should be integrated in a strategy. That way, tactical gains (i.e., successful projects) can be converted in strategic advantages (sustainable profitability or growth).

Since 1900, productivity has increased by enormous factors. In industries like consumer electronics and automotive, production costs (corrected for inflation) have dropped, while at the same time quality has improved by incredible rates. On the one hand, companies cannot afford to fall behind in this race, and continual quality and efficiency improvement is an imperative. Even if a company has other strong advantages, they risk being outweighed if the gap in quality and efficiency becomes large. Six Sigma or a similar approach is a necessity to avoid falling behind in this race.

On the other hand, however, the gains of the enormous increases in quality and efficiency that the 20th century witnessed have gone almost entirely to consumers. There have been only few businesses that managed to convert them into sustainable higher profits over longer periods. While improvement of quality and efficiency may be vital to avoid competitive disadvantage, it is all but straightforward to convert it into competitive advantages and sustained profitability. The reason why this appears so is that superior operations are not something that is unique. All or most competitors are striving for the same, and there is no reason why they should not succeed in achieving a similar level of quality and efficiency, or higher. The standard gets higher, but no company gets ahead. This phenomenon leads to price erosion: when most companies achieve the same improvement in their operations, the principles of competition and the market ensure that prices will decrease by the same amount as costs have, leaving the industry with the same profit margins, and feeding the gains to the consumers. Moreover, in many industries companies are fighting each other over the same issues and by copying each other's moves and best practices (everybody implements the same approaches, be it TQM, JIT, BPR, or Six Sigma) and as a consequence look more and more alike (so called *competitive convergence*). This sort of competition is mutually destructive for companies that participate in it, and the important warning should be that competition over quality and efficiency alone is a poor substitute for a competitive strategy. Hayes and Pisano (1994) and Porter (1996) provide interesting discussions on this topic.

Competitive strategy is a company's attempt to avoid the mechanisms portrayed above (price erosion, competitive convergence). Having said that Six Sigma is unlikely to lead to strategic advantages 'automatically,' it must be stressed that the program offers considerable opportunities for strategic advantages.

Six Sigma should not be started as a substitute for a good strategy. Instead, it should be used to implement, execute, and leverage the strategy that the business has designed, and it should be aligned and integrated with it. Running projects guided by strategic direction ensures that improvements will be achieved where they really make a difference. It ensures that the various projects are integrated and reinforce each other. Alignment with the organization is crucial, as turning the results of successful projects into economic benefits (higher profits, increased market share) usually reaches beyond the scope of the project and the domain of the people who run it.

But besides using Six Sigma as a tactical means to implement and execute a strategy, also Six Sigma itself (or rather: the competencies that it embodies) can be a source of competitive advantage. A company that has truly integrated Six Sigma in its organization is a different company, and one better equipped to face the challenges of the 21st century. Building this competence entails a multitude of tasks. Personnel must be trained in Six Sigma skills. The organizational structures and facilities that the black and green belts need in order to carry out improvement projects effectively should be built. The values that Six Sigma embodies (continuous innovation and improvement, a focus on the customer, data-driven decisions, a relentless focus on the vital few issues that determine performance) must find a wide recognition and acceptance in the organization. And Six Sigma activities, costing substantial time and resources, must find a place alongside regular work.

Such competencies are not built overnight. Integrating Six Sigma in an organization requires careful and tenacious leadership from senior management, and a commitment to a long trajectory. But from a strategic point of view this is good news. Because the development of Six Sigma competencies is a demanding enterprise, it is an opportunity to set oneself apart from competitors and outperform them. Prahalad and Hamel (1990) and Teece et al. (1997) are good introductions to the competence based view on competitive strategy.

SIX SIGMA AS A METHODOLOGY

Six Sigma offers a system of prescriptions for improvement projects. The most tangible elements of this method are the DMAIC (Define Measure Analyze Improve and Control; see Table 1) roadmap, and the statistical and nonstatistical tools and techniques that are taught to black and green belts. There are many descriptions of Six Sigma's method in the literature (Harry, 1997; Pyzdek, 2001, to mention only two). De Koning and De Mast (2006) make a collation of many of these descriptions. This analysis results in two important conclusions:

1. On the face of it, it may seem that accounts given in literature diverge, but analysis shows that variations are superficial rather than essential.
2. Six Sigma's claims of being data-driven and focused on customers and bottom line results appear to be substantiated by its method.

TABLE 1 **Brief Overview of Six Sigma's DMAIC Method**

Define
Problem selection and cost-benefit analysis.
Measure
Translation of the problem into a measurable form, data gathering and assessment of the current situation.
Analyze
Identification of influence factors and causes that determine the process's performance.
Improve
Design and implementation of modifications to the process in order to improve the performance of the process.
Control
Adjustment of the process management and control system to secure that improvements are sustainable.

The five DMAIC phases, often broken down in 12 or another number of steps, embody a number of methodological principles, which we have named Six Sigma's core principles elsewhere (De Mast and Bisgaard, 2007):

1. Improvement actions are based on causal modeling.
2. Inquiry proceeds through an alternation between discovery and justification.
3. Problems are defined in precise and operational terms.
4. Problems are quantified if possible.
5. A data-based diagnosis precedes attempts at solving the problem.
6. Generation of new ideas is daring and imaginative.
7. There is a strong emphasis on data-based testing.

At the heart of Six Sigma's method is the principle that improvement actions are based on understanding of the factors in the process that cause the process's behavior. The equation $Y = f(X_1, X_2, \ldots, X_n)$ is frequently used in Six Sigma to symbolize this principle of causal modeling, Y being the characteristic that needs improvement, and the Xs being the causal factors that determine its behavior. Understanding of the causal mechanisms in a system provides an explanation of its behavior, which serves as a basis to predict and control the system.

Black and green belts are taught to generate ideas about possible causes using an array of approaches: brainstorming, exploratory data analysis, multi-vari studies, product and process examination, and more techniques for hypothesis generation (De Mast and Bergman, 2006, give an overview). Hypothesis generation is speculative in nature, and the pursuit of objectivity or certainty is inappropriate in this context. Objectivity and correctness are guaranteed by the way hypotheses are tested and verified. In Six Sigma, hypothesized causes are experimentally verified using statistically designed experiments or observational data. These two sides of inquiry, hypothesis generation and hypothesis testing, are called *discovery* and *justification* in philosophy of science (De Mast & Bergman, 2006).

Rational problem solving, especially based on causal modeling, is only possible if problems are defined in precise and operational terms. Black and green belts learn to make operational definitions, preferably in the form of quantitative variables which are called *Critical To Quality* (CTQ) characteristics. The need for quantification arises as most interesting problems are trade-off problems. The question is not "either/or," but "how much of one, and how much of the other." Trade-off problems cannot be solved without quantification.

These principles are by no means unique to Six Sigma's method. In fact, similar principles are at the core of scientific method (De Mast, 2003). Six Sigma elevates problem-solving and quality improvement to a more professional level by training black and green belts in an attitude that can be described as *scientific* (Wruck and Jensen, 1994). Empirical research and analysis are emphasized not as a substitute, but as an indispensable supplement to expert knowledge. Six Sigma offers procedures for the study and analysis of problems, rather than standard cures.

Six Sigma's tools and techniques are drawn from a variety of disciplines, but especially from statistical quality control. One finds virtually all the standard techniques that are described in the standard textbooks in that field, such as Duncan (1986) and Montgomery (1991), except for acceptance sampling, which plays virtually no role in Six Sigma. Besides the statistical tools, the toolkit features the simple problem-solving and process analysis tools whose use was widely promoted by the Japanese: process maps, cause and effect matrix, Pareto chart, five why's, et cetera. Especially for the project definition tools borrowed from marketing are used. Six Sigma's tools are advanced, compared to, e.g., Ishikawa's (1982) seven tools, and considering that they are taught to nonstatisticians. But they do in general not reach the level of courses for professional quality engineers or industrial statisticians (see Hoerl, 2001).

SIX SIGMA FROM A STATISTICAL PERSPECTIVE

Six Sigma is frequently associated with statistics. And in fact, the name *Six Sigma* is derived from a statistical line of reasoning. The *sigma metric* is a measure of conformance quality. Various definitions are current, but the basic idea is to express conformance quality as a *Z value*. That is, the characteristic under study is transformed such that it has a standard normal distribution; the position on this transformed scale of the specification limit is the Z value. For a normally distributed $N(\mu, \sigma^2)$ characteristic X with upper specification limit USL, this amounts to

$$Z = (USL - \mu)/\sigma.$$

There are various conventions for dealing with the case that there is a lower and an upper specification limit. One option is to consider only the nearest specification limit:

$$Z = \min\{(USL - \mu)/\sigma, (\mu - LSL)/\sigma\}.$$

Alternatively, one could compute the so-called *benchmark* Z value, which is

$$Z = \Phi^{-1}(d), \qquad (1)$$

with Φ the standard normal distribution function, and d the total fraction nonconforming, $d = \Phi((LSL - \mu)/\sigma) + 1 - \Phi((USL - \mu)/\sigma)$. If X has a nonnormal distribution the Z value is also computed from Eq. [1], be it that d should be computed from another suitable distribution. A wide variety of alternative definitions is current, from which the *1.5 sigma shift* to estimate long-term performance from short-term data is perhaps the most controversial. This rule of thumb says that the long term sigma level is typically 1.5 smaller than the short term level. Following this rule of thumb, a *six sigma process* (i.e., $Z = 6.0$) has, when considered over a 'long' period of time, a sigma level of $Z_{\text{long term}} = 4.5$, which corresponds to a fraction nonconforming of $d = 1 - \Phi(4.5) = 3.4$ ppm (parts per million). It is this conformance level that gave the Six Sigma method its name.

The bearing of statistics on Six Sigma is however much more essential. As indicated above, improvement actions in Six Sigma projects are based on science-like inquiry, in which the relationship between quality characteristics and causal influence factors are studied. Put differently, substantial parts of Six Sigma projects can be considered applied empirical research. As argued frequently (e.g., Box, 1999; Good, 1988), statistics is the discipline that studies and develops methods and paradigms for empirical inquiry. Given the science-like approach that Six Sigma prescribes for studying processes and developing solutions, it is a logical consequence that black and green belts must be taught good research skills, including statistical methods for the collection and analysis of data. The importance of statistics in scientific method is also the essence of the Statistical Thinking movement (Wild and Pfannkuch, 1999), and Six Sigma can be considered a template for the application of statistical thinking to process improvement.

PUTTING IT ALL TOGETHER: A VISION OF A SIX SIGMA COMPANY

In the 21st century, structural changes in markets and industries, technological innovations, fierce and global competition, price erosion, and increasing customer expectations force companies to manage their routine operations well. This implies that organizations must have an effective and efficient system for process development, process improvement and process control.

Most organizations are designed to perform repetitive routine managerial tasks such as manufacturing, accounting and sales. Few if any managerial systems provide a framework for organized and sustained innovation. The exception is of course research and development. While R&D and product and process development have been routinized earlier, Six Sigma offers a management framework to routinize product and process improvement as well.

The purport of Six Sigma's prescriptions for organizing process improvement follows the spirit of economists and management thinkers like Wruck and Jensen (1994) and Mintzberg (1994): swarms of experimental attempts, rather than one grand imperial strategy; process improvement immersed in and not detached from daily detail; and therefore, process improvement as a decentralized activity. Company-wide, all line departments continually improve their processes by running improvement projects, managed and coordinated rather than directed from senior management. Continual improvement becomes an important part of everyone's task.

Projects are run by black and green belts, mostly professionals from the line organization. The training programs they take usually constitute an important step in their career. Six Sigma embodies skills that are imperative requirements of professionals in the 21st century. Data-based decision making, sound inquiry skills, and the ability to formulate a precise problem definition are among the skills that knowledge workers—engineers, managers, marketers, salespersons, and many more—must have. Thus, as Box (1997) aptly said, the proliferation of Six Sigma amounts to a 'democratization of scientific method'. These inquiry skills, including mastery of advanced techniques for data gathering and analysis, constitute a more essential part of Six Sigma's method than the controversial sigma metric and the Six Sigma level of conformance quality as performance objective.

Six Sigma companies employ a host of people trained to have an innovative mindset and professional problem-solving and quality improvement skills. When carefully developed and deployed over time, the cultivation of these competences in an organization can become important sources of competitive advantage. General Electric's carefully built Six Sigma culture exemplifies this.

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