Received July 2004
Revised April 2005

A rational reconstruction of Six-Sigma's breakthrough cookbook

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Abstract

Purpose – The purpose of this paper is to develop a consistent and crystallized exposition of Six-Sigma's methodology for improvement projects, which could serve as a basis for subsequent scientific research of the method.

Design/methodology/approach – The paper shows that reformulation of imprecise and unscientific formulations of knowledge is called rational reconstruction. Starting from accounts given in the Six-Sigma literature, a descriptive reconstruction of the main elements of the Six-Sigma method is made: its business context, strategy, tools and techniques, and concepts and classifications.

Findings – The paper finds that, although, on the face of it, it may seem that accounts given in literature diverge, analysis shows that variations are superficial rather than essential. The analyses result in precisely formulated accounts of Six-Sigma's method (DMAIC phases, steps, and tools), its business context, and its terminology. Essential anomalies are discussed. Six-Sigma's claims of being data-driven and focused on customers and bottom line results appear to be substantiated by its method.

Research limitations/implications – In this paper the presented reconstruction has a purely descriptive impetus: it structures accounts that the Six-Sigma literature itself provides, without critical evaluation against theoretical frameworks beyond the Six-Sigma literature. As such, it provides a basis that is suitable for subsequent scientific research.

Practical implications – The paper sees that loose and inaccurate expositions of Six-Sigma's project methodology are supplemented with a precise formulation.

Originality/value – Among a tide of accounts of Six-Sigma's DMAIC method, this paper provides an account that meets scientific standards of precision and consistency. It allows a substantiation of commonly made claims about Six-Sigma, i.e. Six-Sigma is a quantitative, data-driven approach focused on cause-and-effect relations, and offering new solutions instead of standard cures.

Keywords Research methods, Six sigma, Quality management

Paper type Research paper

Introduction

Six-Sigma is a now widely applied programme for company wide quality improvement. It was developed by Motorola, in the 1980s, but gained enormous momentum, after its adoption by General Electric, in the mid 1990s. Several variants of the approach are current (compare, for instance, Harry, 1997; Breyfogle, 1999; and Pyzdek, 2001), but all variants can be characterized by the programme's customer driven approach, by its emphasis on decision-making based on quantitative data, and by its priority on bottom line results.

The programme prescribes that improvement actions are performed in a project-by-project fashion. It provides an organizational structure, in which improvement projects are led by so called blackbelts and greenbelts, typically

International Journal of Quality & Reliability Management
Vol. 23 No. 7, 2006
pp. 766-787

0265-671X
DOI 10.1108/02656710610701044

selected from middle management. To guide blackbelts and greenbelts through the execution of an improvement project, the programme provides a methodology consisting of a collection of tools and a stepwise strategy: the "Breakthrough Cookbook' or DMAIC method. This stepwise strategy entails four phases: Measure (M), Analyze (A), Improve (I), and Control (C). In more recent accounts of the methodology a five-phase structure is proposed, in which a Define (D) phase precedes the other four.

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" (cf. Stephens, 2003, p. 28). An obstacle to scientific research of Six-Sigma is the absence of a consistent and crystallized exposition of its methodology and philosophy. Present accounts of the method – often written for a non-scientific audience and for different purposes than to serve as a basis for scientific research – do not meet scientific standards of precision and consistency. For example, the demarcation of the phases: Measure, Analyse, Improve and Control, in Harry (1997, p. 21.19) is inconsistent with the steps that these phases are comprised of (p. 21.22). Definitions of concepts such as CTQ (p. 12.20) do not meet scientific standards of precision. Moreover, while most accounts of the methodology agree on the MAIC or DMAIC phase structure, descriptions of the steps that these phases are comprised of and the tools that are prescribed for them diverge.

Given the prominent role that Six-Sigma plays in quality improvement in contemporary business and industry, thorough scientific research of the phenomenon is important. Such research could study, for instance, how Six-Sigma compares to other approaches, under what conditions and for what type of problems the method is suited. Whatever the focus of the study, the scientist will need as a basis a crystallized and consistent formulation of the methodology, and it is the objective of this paper to provide this formulation. Its scope is limited to the methodological elements of the Six-Sigma programme, described together as the Breakthrough Cookbook. The next section describes the different components that Six-Sigma's methodology consists of. Making a more precise and consistent formulation of vaguely and imprecisely formulated knowledge is a type of research that is called rational reconstruction; the next section gives details about this type of studies and specifies the research design for the study that is described in this paper. This paper forms part of a research project, which aims to ground and study the validity of the Six-Sigma method. The design of this research project is expounded in De Koning and De Mast (2005).

Research methodology

The method that Six-Sigma prescribes for its projects is often described as the Breakthrough Cookbook or DMAIC method. It represents a problem-solving method "specifically designed to lead a Six-Sigma Black Belt to significant improvement within a defined process" (Harry, 1997, pp. 21.18-19). It tackles problems in four phases: Measure (M), Analyze (A), Improve (I), and Control (C). In more recent accounts of the methodology a five phase structure is proposed, in which a Define (D) phase precedes the other four (see, e.g. Hahn *et al.*, 2000; more references are given later in this paper). The Breakthrough Cookbook (its phases, steps and toolbox) guides a project leader through his project.

The subject of this study, are the methodological aspects of the Six-Sigma programme as presented in the Breakthrough Cookbook. These are taken to include a description of the type of goals that can be pursued with the method, but all other elements implied by the Six-Sigma programme – project selection, the organizational structure, Six-Sigma and change strategy, training issues – are considered beyond the scope of this study. The Breakthrough Cookbook can be characterized as a system of prescriptions: guidelines that tell a project leader what to do in order to reach a certain goal. Methodologies such as Six-Sigma's Breakthrough Cookbook consist of four classes of elements (De Koning and De Mast, 2005), which are listed and discussed below:

(1) *Business context*. At the background of the Six-Sigma programme is a philosophy that presents a business strategy. This philosophy provides the motivation for implementing the programme by specifying which benefits it is claimed to have, and – of more importance to us – the type of objectives that can be pursued with the methodology. Elements of the business context of Six-Sigma are the hidden factory model and cost of poor quality models.

(2) *Stepwise strategy*. The Breakthrough Cookbook gives a stepwise procedure for tackling projects. Harry (1997), for instance, proposes 12 steps that are grouped in four phases. Steps define end terms (the deliverable of the step) and mostly prescribe in which format they should be documented. For example, the end term of Harry's step 4 is that the process's performance is estimated; this result should be reported in the form of a capability index Z.

(3) *Tools and techniques*. The Six-Sigma programme offers a wide range of procedures that are intended to assist the project leader in attaining intermediate results. Some of these tools and techniques are linked to particular steps of the strategy (e.g., the gauge R&R technique proposed for Harry's step 3, "Validate measurement system"), other are more general (e.g. statistical estimation). Some tools and techniques are statistical, other are nonstatistical.

(4) *Concepts and classifications*. In order to communicate the elements above, the Six-Sigma programme offers concepts (such as the hidden factory and *CTQ*) and classifications (the phases Measure, Analyse, Improve, Control; the distinction between vital Xs and trivial Xs).

The subject of study being Six-Sigma's methodological aspects, considered as a system of prescriptions, and consisting of the four classes of elements introduced above, the objective of the paper is to provide an explicit, precise and consistent reformulation. Explication of vaguely formulated knowledge is called "rational reconstruction". Poser (1980) defines a rational reconstruction as a presentation of the object of reconstruction in a similar, but more precise and more consistent formulation. Here, the object of reconstruction consists of current imprecise formulations of the Six-Sigma methodology. Rational reconstructions can have a descriptive as well as a prescriptive impetus. Descriptive reconstructions focus on clarification and precisation of vague knowledge. Criteria for their accuracy are clarity, exactness and similarity to the original accounts. Prescriptive reconstructions go one step further, by also correcting vague knowledge on the basis of external criteria such as logic or external theories. The criterion of similarity to the original material is compromised to the favour of consistency.

This paper intends to make a descriptive rational reconstruction. It is our intention to present accounts of Six-Sigma's methodology as clear as possible. It is not our intention to evaluate these accounts against external criteria, such as theoretical frameworks in the literature on quality management or methodology. A comparable study is Reed *et al.* (2000), who distill from existing literature a set of core principles of total quality management (TQM). The material that the reconstruction starts from consists of accounts of the four elements mentioned above: business context, stepwise strategy, tools and techniques, concepts and classifications – in the scientific and non-scientific literature. Specifically, we consider articles that have been published in seven journals relevant to industrial statistics:

(1) *Quality Engineering (QE).*
(2) *Quality Progress*.
(3) *Quality and Reliability Engineering International (QREI)*.
(4) *Journal of Quality Technology (JQT).*
(5) *International Journal of Quality and Reliability Management (IJQRM).*
(6) *The American Statistician*.
(7) *International Journal of Six-Sigma and Competitive Advantage*.

In addition, nine books were studied in this research: Harry (1997), Breyfogle (1999), Pyzdek (2001), Harry and Schroeder (2000), Pande *et al.* (2000), Eckes (2001), Creveling *et al.* (2003), Park (2003), and Stephens (2003).

The subsequent sections present our reconstruction of the business context, stepwise strategy, and tools and techniques. Relevant concepts and classifications are reviewed and defined when they are needed.

Reconstruction of the business context

The business context of Six-Sigma refers to the method's purpose. In the studied literature, the usefulness of Six-Sigma is argued from three perspectives:

(1) Showcases, arguing Six-Sigma's usefulness from anecdotal evidence of successful applications.
(2) The hidden factory and cost of poor quality models, which argue Six-Sigma's usefulness from its power to improve a company's cost structure by improving quality.
(3) Strategical benefits associated with improved quality and customer satisfaction, notably, market share increase and reduced price sensitivity.

Showcases

The Six-Sigma literature abounds in showcases, with Motorola, AlliedSignal, and General Electric being the most spectacular ones (see Harry, 1997; Breyfogle, 1999; Hahn *et al.*, 1999; and Pande *et al.*, 2000). Showcases argue the usefulness of Six-Sigma from benefits claimed by companies that implemented the programme, mostly of a monetary form. To give an example, Hahn *et al.* (1999) remark that "The Six-Sigma initiative was at least one key factor in Motorola winning the coveted 1988 Malcolm Baldrige Award for Quality, and produced reported savings of over $940 million in three years."

Hidden factory and cost of poor quality models
Cost of poor quality (COPQ) is "any cost that would not have been expended if quality were perfect" (Pyzdek, 2001, p. 163). In the Six-Sigma literature, COPQ is usually divided in four categories: prevention, appraisal, external, and internal failure costs (Breyfogle, 1999, p. 4). The COPQ concept is used to establish a relation between conformance quality and production costs. The main idea is that conformance quality improvement reduces costs associated with internal or external failure (called cost of lack of control by Wasserman and Lindland, 1996), and of appraisal costs. The hidden factory model makes the same argument: hidden factory refers to all extra activities needed because of nonconformance (Harry, 1997, p. 14.10). Nonconformance results in a larger hidden factory, which brings about higher costs, higher cycle times, higher inventory levels, lower reliability, etc. (see, for example, Harry, 1997, pp. 15.5 and 17.4). Improving conformance quality by deployment of the Six-Sigma programme reduces costs, and this benefit goes directly to the bottom line (Bisgaard and Freiesleben, 2001). What adds to the importance of focusing on conformance quality is that cost of poor quality contains substantial hidden components (Harry, 1997, p. 17.3), which are often ignored or forgotten. Furthermore, the ever-increasing complexity of products and processes leverages the impact of nonconformance onto production cost (Bisgaard and Freiesleben, 2001). Thus, the usefulness of Six-Sigma is argued from its power to tackle quality problems effectively, which is claimed to improve a company's cost structure.

Strategical benefits associated with quality and customer satisfaction
Improved quality, it is argued, results in more value and thus satisfaction for customers (Creveling *et al.*, p. 31). This advantage could be cashed, according to the Six-Sigma literature, either in the form of increased market share, or in the form of higher profit margins (Harry, 1998).

The concept of quality

The term quality plays an important role in the descriptions above, and in fact, Six-Sigma is usually regarded as a quality improvement strategy. This section reconstructs what various authors have in mind when they use the term.

Creveling *et al.* (2003), p. 31) describe quality as a total of product and service characteristics, such as performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality. In line with traditional notions of quality (e.g. quality as "fitness for use"), the customer is taken as the criterion for quality: "Quality [is] performance to standard expected by the customer" (Harry, 1997, p. 3.6). Customer sometimes refers to the end-user, but most authors stretch the meaning of the term to include entities in the producing company: "Many teams make the mistake of assuming that the customer is the external entity that pays the bill" (Eckes, 2001, p. 50), and: "Customer [is] anyone internal or external to the organization who comes in contact with the product or output of my work" (Harry, 1997, p. 3.6). A further generalization of the term quality is introduced by Harry and Schroeder (2000), p. 6): "The Six-Sigma Breakthrough Strategy broadens the definition of quality to include economic value and practical utility to both the company and the customer. We say that quality is a state in which value entitlement is realized for the customer and provider in every aspect of the business relationship."

What do Six-Sigma authors mean when they relate Six-Sigma's benefits to quality improvement? Looking at the third perspective mentioned above (strategical benefits associated with quality and customer satisfaction), it is clear that quality is used to describe properties of products (including services). It is also clear that customer refers to the paying customer. It is proposed to discern this notion as product quality, and to define:

- *Definition*: product quality refers to product characteristics and the extent to which they meet customer (meaning: end-user) demands. Product characteristics that together make up product quality are: performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality.
- *Definition*: Regarding the second perspective above (the hidden factory and cost of poor quality models), quality and quality improvement refer to properties of processes, rather than properties of individual products. In its most limited scope, quality is used as synonymous to process capability.
- *Definition*: process capability refers to the extent to which a process makes products, which are free from defects. The sigma metric of quality is a measure of process quality in this sense. But references to cycle time, yield, and other indicators of "economic value" (in the definition of Harry and Schroeder cited above) suggest a broader definition.
- *Definition*: process quality reflects the demands of internal customers, and comes down to effectiveness (the extent to which a process provides required features) and efficiency (being effective at low cost). Dimensions of process quality include defect rates, but as well cycle time, yield and production costs not related to defects.

It is concluded that the Six-Sigma literature argues the usefulness of the method from its power to improve product quality (which is claimed to result in strategic advantages such as increased market share or reduced price sensitivity) or improve process quality (which is claimed to improve a company's cost structure), both of which are illustrated from showcases. Figure 1 conceptualizes these lines of argumentation.

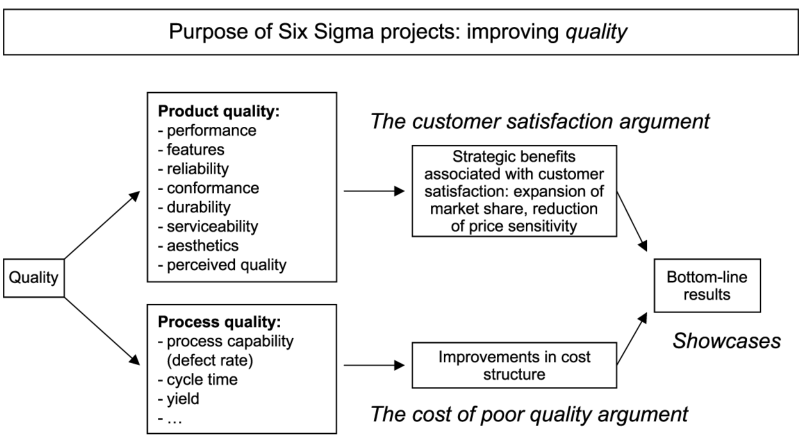

Figure 1.
Rational reconstruction of Six Sigma's business context

Reconstruction of the strategy and step plan

Six-Sigma operationalises its strategy with the help of two types of concepts:

(1) Steps, which either specify the actions a project leader has to perform (for instance: do a process capability analysis), or the intermediate result a project leader has to achieve (for instance: establish the capability of the process), or a combination of both.

(2) Phases, which group together a number of steps.

Before reconstructing Six-Sigma's strategy, several concepts that play important roles in the methodology are studied.

The concepts of CTQ and influence factor

Six-Sigma projects tackle quality problems. The particular subject of a project is made measurable in the form of one or more quality characteristics, which most Six-Sigma authors (Harry, 1997; Hahn *et al.*, 2000; Pande *et al.*, 2000; Rasis *et al.*, 2002; Snee, 2004) call critical to quality characteristics or CTQs. Other terms used to denote the same concept are key process output variables (KPOVs) (Breyfogle, 1999), and Ys (Hahn *et al.*, 1999).

Six-Sigma projects aim to achieve improvement by identifying factors that influence the relevant CTQs (see later in this section). These influence factors, and especially the "vital few", are referred to as Xs, root causes (Hahn *et al.*, 1999; Pande *et al.*, 2000; Eckes, 2001; Rasis *et al.*, 2002; Snee, 2004), key (input) process variables (KPIVs) (Breyfogle, 1999; Hahn *et al.*, 2000), leverage variables or independent variables (Harry, 1997). We define:

- *Definition*: CTQs are dimensions of product and process quality (as defined in the previous section). In particular: CTQs are those quality dimensions on which a Six-Sigma project aims to achieve improvement.
- *Definition*: Influence factors are factors that causally affect the CTQ. The vital few influence factors consist of the group of factors whose effects dominate the effects of all other factors (the trivial many).

Phases: DMAIC

The Six-Sigma method entails a four phase procedure consisting of the phases: Measure (M), Analyze (A), Improve (I) and Control (C); especially in more recent accounts, a Define (D) phase is added before the Measure phase. This MAIC or DMAIC structure is adopted by all authors taken into consideration, except Pyzdek (2001). The basis of the reconstruction of the functionality of these phases is formed by descriptions and definitions taken from the following sources

- 1. Harry (1997, p. 21.7);
- 2. Breyfogle (1999);
- 3. Hahn *et al.* (1999);
- 4. Hahn *et al.* (2000);
- 5. Pande *et al.* (2000, pp. 239, 251, 276, 337); and
- 6. Rasis *et al.* (2002).

Without listing all descriptions and definitions found in these sources, Table I presents a limited number of typical descriptions of each phase's functionality and their source. Based on this material, we constructed definitions of each phase's functionality, which are presented in Table I and discussed below. Since rational reconstructions aim to define the communalities in the various accounts that are used as a source, it is likely that individual accounts deviate from the resulting account. The listing below highlights serious deviations.

Although some descriptions for the Define and Measure phases in the abovementioned sources are clearer than others, there are no serious inconsistencies. The following two definitions are proposed:

(1) *Define phase*: Problem selection and benefit analysis.

(2) *Measure phase*: Translation of the problem into a measurable form, and measurement of the current situation.

The majority of authors is followed in defining the functionality of the Analyze phase as: Identification of influence factors and causes that determine the CTQ's behaviour.

Define	Establishment of the rationale for a Six Sigma project[6] Define the problem to be solved, including customer impact and potential benefits[4] Generic: Problem selection and benefit analysis
Measure	Identify the critical-to-quality characteristics (CTQs) of the product or service. Verify measurement capability. Baseline the current defect rate and set goals for improvement[4] This phase is concerned with selecting one or more product characteristics; i.e. dependent variables, mapping the respective process, making the necessary measurements, recording the results on process "control cards," and estimating the short- and long-term process capability[1] Generic: Translation of the problem into a measurable form, and measurement of the current situation
Analyze	Understand root causes of why defects occur; identify key process variables that cause defects[4] Benchmarking the key product performance metrics. Following this, a gap analysis is often undertaken to identify the common factors of successful performance; i.e. what factors explain best-in-class performance[1] Analyze the preliminary data [collected in the Measure phase] to document current performance (baseline process capability), and to begin identifying root causes of defects (i.e. the "X's", or independent variables) and their impact, and act accordingly[3] Generic: Identification of influence factors and causes that determine the CTQs' behaviour
Improve	Determine how to intervene in the process to significantly reduce the defect levels[3] Generating, selecting, and implementing solutions[5] Generic: Design and implementation of adjustments to the process to improve the performance of the CTQs
Control	Implement ongoing measures and actions to sustain improvement[5] Once the desired improvements have been made, put a system into place to ensure the improvements are sustained, even though significant resources may no longer be focused on the problem[3] Generic: Adjustment of the process management and control system in order that improvements are sustainable

Table I. Rational construction of Six Sigma's phase structure; notes refer to the numbered sources listed in the table

The notable deviation is Hahn *et al.* (1999), who describe the Analyze phase as: "Analyze the preliminary data [collected in the Measure phase] to document current performance (baseline process capability), and to begin identifying root causes of defects (i.e. the 'X's', or independent variables) and their impact and act accordingly." This description implies that besides the identification of causes, also the establishment of the baseline process capability, as well as the implementation of corrective actions are among the functionalities of the Analyze phase in the view of these authors (they are part of, respectively, the Measure and the Improve phase according to the other authors).

The definition of the functionality of the Improve phase captures the ideas of most authors: design and implementation of adjustments to the process to improve the performance of the CTQs.

All authors mention the design of improvement actions as functionality of this phase, but the inclusion, of their implementation, in this phase, is not shared by all authors.

Finally, the definition of the functionality of the Control phase is: Adjustment of the process management and control system in order that improvements are sustainable.

Steps

The functionality of each phase describes its goal. The steps that each phase consists of specify intermediate results and actions. An overview of the steps that various authors provide is given in Table II. The table is based on the following references:

- Harry (1997), p. 21.33 for the Define steps, p. 22.2 for the other steps. The numbers 1 through 12 indicate Harry's numbering of steps.
- Breyfogle (1999), pp. 18-20). The numbers 1a through 21 indicate Breyfogle's numbering. Not all steps of Breyfogle's stepwise strategy are included. Steps 2 and 4 are omitted, because they are related to the organizational context of Six-Sigma. Steps 14, 15, 17 and 18 are omitted, because they refer to specific tools instead of functional steps.
- Hahn *et al.* (2000).
- Pande *et al.* (2000). These authors place the DMAIC method and its steps in an encompassing roadmap for implementation of Six-Sigma in a company (pp. 67-79). As a consequence, many actions have been performed before a DMAIC project starts, and many steps in the Define and Measure phase are reiterations or refinements of these earlier actions. For this reason, Table II lists both the steps prescribed in the preliminary steps of the roadmap (in italics and bracketed, and based on pp. 206-207, 218) and steps listed under the Define and Measure phase (p. 39, but see as well pp. 239, 256, 259, 271, 276-281, 337).
- Eckes (2001), pp.44, 50-55, 59, 71-79, 93-109, 131-137, 173, 205).
- Rasis *et al.* (2002).

Table II collates stepwise strategies proposed by various authors. Shading indicates the authors' allocation of steps to phases. As much as possible, steps with equivalent functionalities are listed in the same row. Our rational reconstruction of the steps of Six-Sigma's method has taken the form of the rightmost column, headed Generic. It was formed, by extracting for each row, the communalities from the steps proposed by

Table II. Reconstruction of Six Sigma's stepwise strategy

Phase	Harry	Breyfogle	Eckes	Pande, Neuman and Cavangh	Rasis, Gitlow and Popovich	Hahn, Doganaksoy and Hoerl	Generic
D		7. Create a flowchart/process map	Create the high-level process map	(Identify "core" business processes Create high-level core process map)	Map processes	Define problem to be solved	D1. Identify and map relevant processes
	Identify customer		Define customers	(Define process outputs and key customers)			D2. Identify targeted stakeholder
	Define needs and specify deliverables Identify CTQs, map process and link CTQs	1a. Identify critical customer requirements from a high level project measurement point of view	Determine needs of customers Define requirements on needs	Identify the problem and define requirements (Gather customer data and develop Voice of Customer strategy. Develop performance standards and requirements statements. Analyze and prioritize requirements; evaluate per business strategy)	Identify issues or concerns relevant to customers. Identify CTQs		D3. Determine and prioritize customer needs and requirements
		1c. Implement a balanced scorecard considering COPQ and RTY metrics 3. Describe business impact. Address financial measurement issues	Make a business case	Set goal	Prepare a business case	Determine potential benefits and determine customer impact	D4. Make a business case for the project
M	1. Select CTQ characteristic	1b. Identify key process output variables (KPOVs) that will be used for project metrics	Identify measures of: input (supplier effectiveness) process measures (your efficiency) output measures (your effectiveness)	(Select what to measure)	Study and understand CTQs	Identify the critical-to-quality characteristics (CTQs) of the product or service	M1. Select one or more CTQs

(*continued*)

Table II.

Phase	Harry	Breyfogle	Eckes	Pande, Neuman and Cavangh	Rasis, Gitlow and Popovich	Hahn, Doganaksoy and Hoerl	Generic
	2. Define performance standards		Make operational definitions	(Develop operational definitions)	Develop operational definitions for each CTQ variable		M2. Determine operational definitions for CTQs and requirements
	3. Validate measurement system	10. Conduct a measurement systems analysis. Consider a variance component analysis		(Test measurement accuracy and value)	Perform a GRR study for each CTQ	Verify measurement capability	M3. Validate measurement system of the CTQs
A	4. Establish product capability	5. Start compiling project metrics in a time series format. Utilize a sampling frequency that reflects "long-term" variability. Create run charts and control charts of KPOVs 6. Determine "long-term" process capability/performance of KPOVs. Quantify nonconformance proportion. Determine baseline performance	Baseline sigma level of process and determine variation types	Validate problem (Develop baseline defect measures)	Establish baseline capabilities for each CTQ	Baseline the current defect rate	M4 Assess the current process capability
	5. Define performance objectives			Refine problem/goal		Set goals for improvement	M5. Define objectives.
				Measure key steps/inputs	Determine key measures for upstream suppliers, inputs and processes and collect baseline data for those measures		

(continued)

Table II.

Phase	Harry	Breyfogle	Eckes	Pande, Neuman and Cavangh	Rasis, Gitlow and Popovich	Hahn, Doganaksoy and Hoerl	Generic
	6. Identify variation sources	8 and 9. Create a fishbone diagram to identify variables that can affect the process output; Create a cause and effect matrix assessing the strength of relationships thought to exist between KPIVs and KPOVs	Brainstorm all the possible ideas that could explain the Y	Develop causal hypotheses	Identify upstream Xs for the CTQs	Understand the root causes of why defects occur and identify key process variables that cause defects	A1. Identify potential influence factors.
					Operationally define, perform a GRR analysis for and baseline each X. Control the Xs for each CTQ		
	7. Screen potential causes	11. Rank importance of key process influence factors (KPIVs) using a Pareto chart	Cull down the large number of ideas to a more manageable number Reduce the causes down to the vital few	Identify "vital few" root causes Validate hypothesis	Identify the major noise variables for each CTQ Understand the effect of the Xs on each CTQ Determine the "vital few" Xs for each CTQ		A2. Select the vital few influence factors.
		12. Prepare a focused FMEA. Assess current control plans					
I	8. Discover variable relationship	13 and 16. Collect data for assessing the KPIV/KPOV relationships that are thought to exist			Understand the relationship between CTQs and high risk Xs/major noise variables	Quantify influences of key process variables on the CTQs	I1. Quantify relationship between Xs and CTQs

(*continued*)

Phase	Harry	Breyfogle	Eckes	Pande, Neuman and Cavangh	Rasis, Gitlow and Popovich	Hahn, Doganaksoy and Hoerl	Generic
	9. Establish operating tolerances	19. Determine optimum operating windows of KPIVs from DOEs and other tools	Generate and implement solutions that either eliminate the root cause, soften or dampen the effects of the root cause, or neutralize root causation effects	Develop ideas to remove root causes	Generate actions needed to implement the optimal levels of vital few Xs that optimize spread, center and shape of CTQs Develop action plans	Identify acceptable limits of the key process variables and modify the process to stay within these limits, thereby reducing defect levels in the CTQs	I2. Design actions to modify the process or settings of influence factors in such a way that the CTQs are optimized
				Test solutions	Conduct pilot tests of actions		I3. Conduct pilot test of improvement actions
C	10. Validate measurement system (of Xs)						
	11. Determine process capability	21. Verify process improvements, stability, and capability/performance using demonstration runs		Standardize solution/measure results			C1. Determine the new process capability
	12. Implement process controls	20. Update control plan. Implement control charts to timely identify special cause excursions of KPIVs	Implement process controls to hold the gains	Establish standard measures to maintain performance Correct problems as needed	Lock-in improvements by developing, documenting, and implementing process control plans for all high risk Xs and CTQs	Ensure that the modified process now keeps the key process variables within acceptable limits in order to maintain the gains long-term	C2. Implement control plans

Table II.

the selected authors, and formulating these communalities, in a more generic terminology.

Table II shows that there is considerable agreement among authors about the steps that should be given to project leaders as guidelines for their projects, although most authors omit one or a few steps. Consequently, the generic steps can be considered an adequate reconstruction of Six-Sigma's stepwise strategy. Nevertheless, deviations can be noted in the form of omissions, additions, and differences in order. We discuss the most salient ones.

Omitted steps

Many authors omit one or more steps, and especially about the steps in the Define phase there is less unanimity. In subsequent phases, step M5 (Define objectives) is listed by only half of the authors. Pande, Neuman and Cavanagh as well as Eckes omit the quantification of the relation between influence factors and CTQs (I1). They see the quality problem as a consequence of one or a few root causes. Probably as a consequence of this, the emphasis is less on estimation of a transfer function, but more on the identification of the root cause – once it is tracked down, improvement is seen as straightforward. Step I3 (Conduct pilot test of improvement actions) is listed by only two authors. In the Control phase only Harry; Breyfogle; and Pande, Neuman and Cavanagh propose to assess the capability of the improved process (C1).

Added steps

Rasis, Gitlow and Popovich add a step between the Measure and Analyze phase in which key measures for upstream suppliers, inputs and processes are determined and baseline data for those measures are collected. A second addition is a step placed after the identification of possible influence factors in which these are operationally defined, baselined and a measurement system analysis is done. Harry as well adds the validation of the measurement system of the Xs as an extra step, but only after the Improve phase. Both additions make sense, in view of the fact that similar actions are done for the CTQs. Because most authors do not include these steps, they were not incorporated in the generic steps. Finally, Breyfogle suggests to assess current control plans at the end of the Analyze phase. It is not abundantly clear to what end one should this.

Differences in ordering

Breyfogle's step plan is the only one with an order that is very distinctive from the generic steps. At odds with other authors, he places the validation of the measurement system (his step 10; generic step M3) after the identification of influence factors. Moreover the creation of a flowchart or process map (his step 7) takes place between the Measure and Analyze phase. Other accounts place process mapping early in the Define phase (D1).

Steps and phases combined

Steps provide an operationalization of the functionality of the phases. This section comments briefly on the consistency of the stated functionality of each phase and the steps that it consists of, also addressing some additional methodological prescriptions that individual authors make.

The steps D1-D4 that the Define phase consists of agree with its functionality. The same holds for the steps that the Measure phase consists of, except that step M5 (Define objectives) is not implied in the phase's functionality. It is preserved in the reconstruction because one could argue that this step comes down to a verification and possible adjustment (based on the assessed current capability) of the business case that was established in the Define phase (step D5). Another anomaly is Harry (1997), who lists his steps 4 and 5 (which correspond to generic steps M4 and M5) under the Analyze phase, which seems at odds with even his own description of the Measure and Analyze phase (p. 21.19).

The steps A1 and A2 agree with the stated functionality of the Analyze phase, and a similar conclusion holds for steps I1, I2 and I3 of the Improve phase. Most authors imply that step I2 (Design actions to modify the process or settings of influence factors in such a way that the CTQs are optimised) is based on quantified relations between influence factors and CTQs (so called transfer functions). Together with step I1 (Quantify the relationship between Xs and CTQs) this shows that Six-Sigma prescribes that improvement actions should be derived from discovered causal relationships between influence factors and CTQs. In the formulation of step I2 in the corresponding steps of Harry (1997), Breyfogle (1999), and Hahn *et al.* (2000) improvement actions are limited to the design of suitable tolerance limits, but it is questionable whether this restriction is really the authors' intention.

Comparing steps C1 and C2 to the stated functionality of the Control phase, it appears that C1 (Determine the new process capability) does not relate directly to the Control phase's functionality (Adjustment of the process management and control system in order that improvements are sustainable). In view of the fact that C1 is logical in its place, we revise the formulation of the Control phase's functionality: empirical verification of the project's results and adjustment of the process management and control system in order that improvements are sustainable.

This section is concluded by addressing additional and deviating methodological prescriptions that are raised by various authors.

Pande *et al.* (2000) place the DMAIC method and its steps in an encompassing roadmap for implementation of Six-Sigma in a company (pp. 67-79). The five steps are:

(1) Identify core processes and key customers.
(2) Define customer requirements.
(3) Measure current performance.
(4) Prioritize, analyze, and implement improvements.
(5) Expand and integrate the Six-Sigma system.

Steps 1, 2, and 3 are done for the whole company and help select improvement projects. A "voice of the customer system" is built, which measures performance on a wide range of characteristics. The fourth step consists of Six-Sigma projects and encompasses the DMAIC phases.

Also Harry (1997) places improvement projects (the inner MAIC loop) in an encompassing roadmap (the outer MAIC loop; see pp. 21.18-23). The outer loop, performed by management and technical leaders, encompasses selection and execution of the phases Measure (product benchmarking), Analyze (process baseline analysis), Improve (the improvement projects, following the inner MAIC loop), and Control (audit and review).

Some authors mention an extra methodological rule: improvement and/or analysis has an iterative nature (Pande *et al.*, 2000, p. 239, call this the "back-and-forth nature of process improvement"). This means that several iterations of the Improvement phase might be needed (Hahn *et al.*, 1999). Along the same lines Harry (1998), p. 62) argues that "... it may be necessary to revisit one or more of the preceding phases." One might even have to reconsider the project's initial goals (Pande *et al.*, 2000, p.239).

Reconstruction of Six-Sigma's toolbox

Besides a business context and a strategy, Six-Sigma provides a collection of tools. This section gives an overview of tools per DMAIC step. Tools come in various forms, such as models, analysis templates, and procedures. They intend to assist the project leader to obtain intermediate results within steps. This section gives an overview of the tools that are prescribed for each of the DMAIC phases. The following sources are used:

- Harry (1997), pp. 21.37-21.38, 22.4-22.47) (for applications in service quality, Harry lists tools assigned to particular phases. For general projects, tools are listed without reference to particular phases; the assignment to phases below was done by us).
- Breyfogle (1999).
- Hahn *et al.* (1999).
- Pande *et al.* (2000), pp. 168, 181, 192-193, 209, 212-217, 218, 257-269, 277-281, 343, 346, 351, 356-373) (Most tools are assigned to phases; when the link was absent, the assignment was done by us).
- 5. Eckes (2001), pp. 52-3, 73, 114-148, 175, 210-212).
- 6. Hoerl (2001).
- 7. Rasis *et al.* (2002).

Upon studying Table III, one could conclude that Six-Sigma's toolkit draws heavily from the field of statistical quality control (SQC, or industrial statistics and quality engineering). One finds virtually all the standard techniques that are described in the standard textbooks in that field, such as Montgomery (1991) and Duncan (1986), except for acceptance sampling, which plays a very modest role (if any at all) in Six-Sigma. Besides the statistical SQC tools, Six-Sigma's 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, etc.

The SQC-based toolbox is supplemented with techniques borrowed from marketing: focus groups, customer interviews, survey studies, and the like (cf. the tools listed under the Define phase).

For some tools, such as reliability engineering and lean manufacturing, the functionality within Six-Sigma is not clear to the authors. Lean manufacturing and reliability engineering seem a bit odd in the Six-Sigma toolbox, being complete approaches in themselves, rather than tools. They are listed, only by Breyfogle (1999).

Phase	Tool	Functionality
General	Check sheet	Data analysis
General	Data collection plan, form, sheet[1,2]	Data analysis
General	Bar chart[1,5,6]	Data analysis
General	Pie chart[1,5,6]	Data analysis
General	Box plot[2]	Data analysis
General	Line chart[1,5,6]	Data analysis
General	Histogram[1,2,5,6]	Data analysis
General	Sampling[1,2,4,5,6]	Data analysis
General	Descriptive statistics[1,2]	Data analysis
Define	Process mapping, flowchart, SIPOC model[1,2,3,4,5,6,7]	Identify and map relevant processes
Define	Customer interview[4,5]	Determine and prioritize customer needs and requirements
Define	Survey[1,4,5]	Determine and prioritize customer needs and requirements
Define	Focus group[4,5]	Determine and prioritize customer needs and requirements
Define	Customer observation[4,5]	Determine and prioritize customer needs and requirements
Define	Customer complaint system[4,5]	Determine and prioritize customer needs and requirements
Define	Voice of the customer analysis[7]	Identify concerns important to customers
Define	Kano's model[4,7]	Determine and prioritize customer needs and requirements; classification of customer requirements into dissatisfiers, satisfiers, and delighters
Define	Quality function deployment[2,3,4,6,7]	Adjust the online quality control system; keep track of processed products
Define	CTQ tree, tree diagram, CTQ flowdown[1,4,5]	Determine and prioritize customer needs and requirements
Define	Affinity diagram[2,4,5,6]	Determine and prioritize customer needs and requirements
Define	Interrelationship diagraph[2,6]	Determine and prioritize customer needs and requirements; identification and classification of needs and requirements
Measure	Pareto chart[1,2,4,5]	Select one or more CTQs
Measure	Failure modes and effects analysis[1,2,6,7]	Select one or more CTQs
Measure Unit, defect and opportunity[1,4,5]	Determine operational definitions for CTQs and requirements	
Measure	Measurement system analysis, Gauge R&R study[1,2,3,4,6,7]	Validate measurement system of the CTQs
Measure	Control chart[1,2,4,5,6,7]	Process capability analysis
Measure	Process capability analysis[1,2,3,5,6,7]	Assess the current process capability
Measure	Capability index[1,2,5]	Process capability analysis
Measure	Probability plot[2,7]	Process capability analysis
Measure	Benchmarking[1,2,4,5]	Adjust the online quality control system; keep track of processed products
Analyze	Cause and effect or fishbone diagram[1,2,4,5]	Identify potential influence factors
Analyze	Brainstorming[1,2,4,5]	Identify potential influence factors
Analyze	Process map, flowchart[4,5]	Identify potential influence factors
Analyze	Value stream map[4,5]	Identify potential influence factors; identify process inefficiencies

(*continued*)

Table III.
Rational reconstruction of Six Sigma's toolbox; notes refer to the numbered sources listed above

Phase	Tool	Functionality
Analyze	Data mining[7]	Identify potential influence factors
Analyze	Screening experimental design[2,7]	Identify potential influence factors
Analyze	Transmission of variance analysis[2]	Identify potential influence factors
Analyze	Five why's[1,5]	Adjust the online quality control system; keep track of processed products
Analyze	Exploratory data analysis tools[1,2,4,5]	Identify potential influence factors
Analyze	Cause and effect matrix[1,2]	Select the vital few influence factors; keep track of influence factors
Analyze	Statistical significance tests (chi-square test, *t*-test, (M)ANOVA, hypothesis testing, confidence intervals, regression analysis)[1,2,3,4,5,6]	Select the vital few influence factors
Analyze	Design of experiments[1,2,3,4,5,6,7]	Select the vital few influence factors
Analyze	Logical cause analysis[4]	Select the vital few influence factors
Analyze	Bootstrapping[2]	Select the vital few influence factors; establishment of confidence intervals on estimates
Improve	Statistical model building[1,2,3,4,5,6]	Quantify relationship between influence factors and CTQs
Improve	Design and analysis of experiments[1,2,3,4,5,6,7]	Quantify relationship between influence factors and CTQs
Improve	Response surface methodology[1,2,3,4]	Quantify relationship between influence factors and CTQs
Improve	Tolerance design[1]	Design improvement actions; determination of specification levels for influence factors
Improve	Robust design[2]	Design improvement actions
Improve	Benchmarking[1,2,4,5]	Design improvement actions
Improve	Brainstorming[1,2,4,5]	Design improvement actions
Improve	Affinity diagram[2,4,5]	Design improvement actions
Improve	Application of Must and Want criteria[5]	Adjust the online quality control system; keep track of processed products
Control	Statistical significance test[1,2,3,4,5,6]	Determine the new process capability; demonstrate improvement
Control	Process capability analysis[1,2,3,4,5,6]	Determine the new process capability; demonstrate improvement
Control	Mistake proofing, Poka Yoke[2,3,4,6,7]	Adjust the online quality control system
Control	Control plans[3,4,5,6,7]	Adjust the online quality control system
Control	Process scorecard[4]	Adjust the online quality control system
Control	Statistical process control[1,2,4,5,6]	Adjust the online quality control system
Control	Control chart[1,2,45,6,7]	Adjust the online quality control system
Control	Pre-control chart[2]	Adjust the online quality control system
Control	Gantt chart, schedule[5]	Adjust the online quality control system; keep track of processed products
Control	Checklist[5]	Adjust the online quality control system
Control	Audit[5]	Adjust the online quality control system
Control	Failure modes and effects analysis[1,2,4,6,7]	Adjust the online quality control system
Control	Risk management[7]	Adjust the online quality control system
Control	Lean manufacturing[2]	Adjust the online quality control system; streamline processes; functionality within Six Sigma not clear
Control	Reliability engineering[2]	Adjust the online quality control system; functionality within Six Sigma not clear

Table III.

Discussion

The reconstruction in this paper is purely descriptive. That is, it structures the accounts that the Six-Sigma literature itself provides, without evaluating them against theoretical frameworks beyond the Six-Sigma literature. A partial prescriptive reconstruction is given by, for example, De Mast (2003), which focuses on the stepwise strategy.

The reconstruction that this paper provides is intended to serve as a basis for scientific studies. We mention two applications of the results of this paper in scientific research:

(1) Compare Six-Sigma with and position it with respect to other approaches.

(2) Study the method's applicability (under what conditions and for what type of problems does the method work?). For example: is the same method suitable for both the manufacturing and service industry?

The main result of the study consists of a structured account of the Six-Sigma method, as provided by Figure 1, and Tables I, II and III. Furthermore, the reconstruction allows us to draw a number of conclusions about Six-Sigma, which characterise the method:

(1) Project selection is customer-focused (as opposed to being driven by technology, experts, or perception), and starts from an inventory of customer needs. Typically, the term customer here refers to either the end-user (projects focusing on product quality) or the company (projects focusing on process quality). Support for this conclusion, is provided by generic steps D2 (identify targeted stakeholder) and D3 (determine and prioritize customer needs and requirements), and the inclusion of tools for analyzing the voice of the customer (such as customer interviews and focus groups).

(2) The method prescribes that problems and issues be parameterized. Problems and issues are translated into the form of variables and requirements, thus providing an unambiguous and operational definition of the problem under study. Cf. steps M1 (select one or more CTQs) and M2 (Determine operational definitions for CTQs and requirements).

(3) Emphasis is on quantification: variables are preferably numeric, and the magnitude of problems or the effects of influence factors should be quantified. This enables priorization and optimization of interaction effects and trade-offs, as embodied in techniques like the Pareto analysis and response surface methodology.

(4) Relationships among variables are modelled: strategic goals (whether customer demands or the company's strategic focal points) are related to CTQs. The CTQs' behaviour in turn is related to influence factors that causally affect it. Thus, improvement actions are based on understanding of relationships among factors and on the discovery of causal mechanisms. Generic step I1 (quantify relationship between Xs and CTQs), as well as tools such as the CTQ flowdown, quality function deployment, and the many statistical modelling tools like regression analysis all support this conclusion.

(5) Ideas are tested to empirical reality. One of Six-Sigma's maxims reads "Show me the data". During projects, this means that a data based problem diagnosis

precedes attempts at solving the problem that the hypothesized effects of influence factors are experimentally studied, and that improvement actions are tested in practice before they are accepted. More in general, one could say that Six-Sigma emphasises empirical research and analysis, not as a substitute, but as an indispensable supplement to expert knowledge. See, for instance, steps such as M4 (assess the current process capability), A2 (select the vital few influence factors), and I3 (conduct pilot test of improvement actions), and tools such as the capability analysis, design of experiments, and statistical significance tests.

(6) Six-Sigma does not offer standard cures, but a method for gaining understanding of the causal mechanisms underlying a problem. Two directions could be discerned in the type of improvements that Six-Sigma prescribes. On the one hand is the view put forward by Harry (1997), Breyfogle (1999), Hahn *et al.* (2000), and Rasis *et al.* (2002), who advise the project leader to find a transfer function that quantifies the effect of influence factors onto the CTQ (step I1). Influence factors are described as variables, rather than disturbances or events. Improvement actions exploit the knowledge of this relationship, and could take the form of optimization of process settings, the economical design of tolerances, or pointed countermeasures against noise variables. On the other hand is the view put forward by Pande *et al.* (2000) and Eckes (2001), who are less focused on finding a transfer function. Their description of improvement actions is more general, for instance, "remove root causes."

(7) Tools and techniques are advanced, considering that they are taught to non-statisticians (compared to, e.g. Ishikawa (1982) seven tools). But they do in general not reach the level of courses for professional quality engineers or industrial statisticians (see Hoerl, 2001). Tools and techniques are drawn from various disciplines, but especially SQC and marketing.

Conclusions

(1) Six-Sigma's methodology is a system of prescriptions; it consists of four classes of elements, namely a description of the type of purposes for which it applies, a stepwise strategy, a collection of tools, and concepts and classifications.

(2) Comparison of various descriptions of the method, demonstrates that these descriptions have enough communalities to consider them as variations of a single method, and therefore to allow a meaningful reconstruction of their shared essence.

(3) Six-Sigma's approach to process improvement is heavily based on the theory of empirical inquiry, as well for the method it prescribes (modelling of the causal structure that underlies a problem), as for its approach (empirical study of hypotheses), and for its tools (statistical tools for empirical research).

(4) Six-Sigma offers procedures for the study and analysis of problems, rather than standard cures.

References

Bisgaard, S. and Freiesleben, J. (2001), "Economics of Six-Sigma programs – quality quandaries", *Quality Engineering*, Vol. 13 No. 2, pp. 325-31.

Breyfogle, F.W. (1999), *Implementing Six-Sigma – Smarter Solutions Using Statistical Methods*, Wiley, New York, NY.

Creveling, C.M., Slutsky, J.L. and Antis, D. (2003), *Design for Six-Sigma – In Technology and Product Development*, Prentice-Hall, Englewood Cliffs, NJ.

De Koning, H. and De Mast, J. (2005), "Grounding of Six-Sigma's breakthrough cookbook: how to research a methodology?", *International Journal of Six-Sigma and Competitive Advantage*, Vol. 1 No. 3.

De Mast, J. (2003), "Quality improvement from the viewpoint of statistical method", *Quality and Reliability Engineering International*, Vol. 19 No. 4, pp. 255-64.

Duncan, A.J. (1986), *Quality Control and Industrial Statistics*, 5th ed., Irwin, Homewood, IL.

Eckes, G. (2001), *The Six-Sigma Revolution – How General Electric and Others Turned Process into Profit*, Wiley, New York, NY.

Hahn, G.J., Doganaksoy, N. and Hoerl, R.W. (2000), "The evolution of Six-Sigma", *Quality Engineering*, Vol. 12 No. 3, pp. 317-26.

Hahn, G.J., Hill, W.J., Hoerl, R.W. and Zinkgraf, S.A. (1999), "The impact of Six-Sigma improvement – a glimpse into the future of statistics", *The American Statistician*, Vol. 53 No. 3, pp. 208-15.

Harry, M.J. (1997), *The Vision of Six-Sigma*, 5th ed., Tri Star, Phoenix, AZ.

Harry, M.J. (1998), "Six-Sigma: a breakthrough strategy for profitability", *Quality Progress*, Vol. 31, May, pp. 60-4.

Harry, M.J. and Schroeder, R. (2000), *Six-Sigma – The Breakthrough Management Strategy Revolutionizing the World's Top Corporations*, Doubleday, New York, NY.

Hoerl, R.W. (2001), "Six-Sigma black belts: what do they need to know?", *Journal of Quality Technology*, Vol. 33 No. 4, pp. 391-406.

Ishikawa, K. (1982), *Guide to Quality Control*, Asian Productivity Organization, Tokyo.

Linderman, K., Schroeder, R.G., Zaheer, S. and Choo, A.S. (2003), "Six-Sigma: a goal-theoretic perspective", *Journal of Operations Management*, Vol. 21 No. 2, pp. 193-203.

Montgomery, D.C. (1991), *Statistical Quality Control*, 2nd ed., Wiley, New York, NY.

Pande, P.S., Neuman, R.P. and Cavanagh, R.R. (2000), *The Six-Sigma Way – How GE, Motorola, and Other Top Companies Are Honing Their Performance*, McGraw-Hill, New York, NY.

Park, S.H. (2003), *Sig Sigma for Quality and Productivity Promotion*, Asian Productivity Organization, Tokyo.

Poser, H. (1980), in Speck, J. (Ed.), *Handbuch wissenschaftstheoretischer Begriffe, Band 3*, Vandenhoeck und Ruprecht, Göttingen, pp. 555-6.

Pyzdek, T. (2001), *The Six-Sigma Handbook – a Complete Guide for Greenbelts, Blackbelts, and Managers at All Levels*, McGraw-Hill, New York, NY.

Rasis, D., Gitlow, H. and Popovich, E. (2002), "Paper organizers international: a fictitious Six-Sigma green belt case study I", *Quality Engineering*, Vol. 15 No. 2, pp. 127-45.

Reed, R., Lemak, D.J. and Mero, N.P. (2000), "Total quality management and sustainable competitive advantage", *Journal of Quality Management*, Vol. 5, pp. 5-26.

Snee, R.D. (2004), "Six-Sigma: the evolution of 100 years of business improvement methodology", *International Journal of Six-Sigma and Competitive Advantage*, Vol. 1 No. 1, pp. 4-20.

Stephens, K.S. (2003), *Six-Sigma and Related Studies in the Quality Disciplines – The Best on Quality*, No. 14, ASQ Quality Press, Milwaukee, WI.

Wasserman, G.S. and Lindland, J.L. (1996), "A case study illustrating the existence of dynamics in traditional cost-of-quality models", *Quality Engineering*, Vol. 9 No. 1, pp. 119-28.

Further reading

Juran, J.M. (1989), *Juran on Leadership for Quality – An Executive Handbook*, Free Press, New York, NY.

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