Grounding of Six Sigma's Breakthrough Cookbook: how to research a methodology?

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Abstract: The Six Sigma programme has developed into a standard for quality and efficiency improvement in business and industry. This fact makes scientific research into the validity and applicability of this methodology important. This article explores the possibilities of a scientific study of the methodological aspects of the Six Sigma programme, and its Breakthrough Cookbook in particular. The objective of the paper is to provide researchers with a scientifically sound approach for studying the validity and applicability of a methodology such as Six Sigma. Several research methodologies are considered, whereupon a grounding research approach is developed. A comparison of the results of a literature review and the proposed research plan learns that current literature on the methodological aspects of Six Sigma does not meet scientific standards of precision and consistency.

Keywords: quality improvement strategy; DMAIC; grounding research; research of methodologies.

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1 Introduction

In order to introduce statistical methods for quality improvement and control in a coherent and operational form in business and industry, numerous statistical programmes and approaches have been proposed. In the 1980s and 1990s, Taguchi's methods and the Shainin System were commonly applied in statistical process control. The 1990s saw the appearance of the Six Sigma programme as a standard for quantitative quality improvement. De Mast (2004) presents a methodological comparison of Taguchi's methods, the Shainin System and the Six Sigma approach.

Scientific investigation of statistical improvement programmes, such as the ones mentioned above, should provide a better understanding of these approaches, and suggest directions for improvement. Such an investigation confronts the scientist, however, with the problem that statistical improvement programmes have many aspects, belonging to different disciplines in science, such as statistics, methodology, management science, economics, and quality engineering. And although many of these aspects can be studied using standard research approaches, there will be aspects for which scientists cannot fall back on a standard approach, but are forced to work out a research design themselves.

This article explores the required research methodology for a scientific study of the Six Sigma programme. The envisaged study focuses on the methodological aspects of the programme, as presented in the programme's Breakthrough Cookbook. The objective of the paper is to provide researchers with a scientifically sound approach for studying the validity and applicability of a methodology such as Six Sigma.

The article starts with a demarcation and precise definition of the subject of study and an enumeration of the elements that it encompasses. Section 3 considers three alternative research approaches for studying the adequacy of methodologies: an empirical approach, a reconstruction approach, and an approach that could be described as *grounding research*. This investigation results in a research plan that outlines which steps a researcher would have to take to adequately ground the validity of Six Sigma's methodology. The fourth section presents and discusses the results of a literature study, which makes an inventory of relevant articles on the subject. Finally, and based on the rest of the account, the paper motivates the relevance of the envisaged study and positions it in the discipline of industrial statistics.

2 Subject of study

2.1 Six Sigma's Breakthrough Cookbook

Six Sigma is a philosophy for company-wide quality improvement. It was developed by Motorola and popularised by General Electric. Several variants are current (Harry, 1997; Breyfogle, 1999; Pyzdek, 2001). We focus here on the variant as presented by Harry (1997).

The programme is characterised by its customer-driven approach, by its emphasis on decision making based on quantitative data, and by its priority on saving money. The selection of projects is based on these three aspects. Part of the Six Sigma programme is a 12-step 'Breakthrough Cookbook' (Inner MAIC-loop), 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), Analyse (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. Each of the phases M, A, I, and C encompasses three steps, which guide a project leader in the execution of a quality improvement project (see Table 1). The Breakthrough Cookbook is part of an embracing strategy – the Outer MAIC-loop – which comprises the strategic coordination of improvement projects (Harry, 1997,pp.21.21–22).

The subject of the study considered in this paper is the Breakthrough Cookbook (BC) and the tools that it prescribes. All other elements implied by the Six Sigma programme – project selection, the organisational structure, change strategies, training issues – are not taken into account.

Table 1 Six Sigma Breakthrough Cookbook

Define	
Measure	1. Select CTQ characteristic
	2. Define performance standards
	3. Validate measurement system
Analyse	4. Establish product capability
	5. Define performance objectives
	6. Identify variation sources
Improve	7. Screen potential causes
	8. Discover variable relationships
	9. Establish operating tolerances
Control	10. Validate measurement system
	11. Determine process capability
	12. Implement process controls

Source: Harry (1997)

2.2 Characterisation of the BC as knowledge

We could characterise the subject of study – Six Sigma's BC – as a *system of prescriptions*: guidelines that tell a project leader what to do in order to reach a certain goal. Upon closer investigation, we could discern the following elements:

- *Application context*

  At the background of the BC is a philosophy that presents a business strategy. We obtain a conceptual model for business processes: the 'hidden factory' model, which places besides the regular production processes all those activities that are required to deal with the problem of nonconforming products (Harry, 1997,p.14.10). From this model a strategy is derived, which centres around the conviction that it is lucrative to reduce defect rates down to extreme low percentages. Other characteristics of the approach are: a focus on the demands of customers, and an emphasis on data-driven improvement projects.

- *Strategy*

  The BC gives a stepwise procedure. The 12 steps are grouped in four phases. Each step defines an end term ('When is the step completed?') and the format in which the end term should be documented. For example, the end term of Step 4 is that the process's performance is estimated; this should be documented in the form of a capability index Z. The end term of Step 8 is that the relation between the CTQ and the vital Xs is known; this should be documented in the form of a transfer function.

- *Tools and techniques*

  The BC offers a wide range of procedures that are intended to assist the project leader in attaining the end terms stated in the steps of the strategy. Some of these tools and techniques are linked to particular steps of the strategy (*e.g.*, the procedure called *gauge R&R study* for Step 3); others are more general (*e.g.*, statistical estimation). Some tools and techniques are statistical; others are nonstatistical (*e.g.*, brainstorming, quality function deployment, failure mode, and effects analysis).

- *Concepts and classifications*

  In order to communicate all the elements above, the BC offers a terminology (concepts such as the *hidden factory*, *CTQ*, *opportunity*) and classifications (the phases *Measure, Analyse, Improve, Control*; the distinction between *vital Xs* and *trivial Xs*).

2.3 Demarcation of the subject of study

In this paper we develop a research methodology to make a scientific study of the validity and applicability of a system of prescriptions such as the BC, and in particular its application context, strategy, tools and techniques, and concepts and classifications. In the succeeding section we consider various research methodologies to guide this study.

3 Research methodology

It will be clear that a study of the BC cannot be undertaken following the formal type of research that is common in mathematics, where theorems are derived by certain rules of deduction from a set of axioms. We examine how a scientific investigation of a system of prescriptions could be approached.

3.1 Empirical research

One could consider to study the BC following the approach of empirical research. One would, in that case, regard prescriptions (or rather, their application and the outcome of their application) as empirical phenomena. Measuring the success of their application, one could single out the successful elements of the BC from the less successful.

Although the study of records of past uses is an important element of the approach that we envisage, we propose an approach that goes further. Merely recording which prescriptions correlate with successful applications and which do not, gives no explanation of the way the BC works. In order to gain insight in how successful prescriptions work, we must understand the internal logic of the BC.

3.2 Reconstruction research

A second approach would be to understand the BC as an attempt to reconstruct the unspoken 'know-how' that skilled project leaders have collected during years of experience with quality improvement projects in the form of heuristics, best practices, and intuition. A major part of this know-how is 'tacit' knowledge – that is, knowledge which works in the background of consciousness and directs attention and action, but which is not made explicit or linguistically codified (the notion of tacit knowledge was put forward by Polanyi, 1958). The BC could be regarded as an attempt to structure and explicate this tacit knowledge in order to facilitate the transfer of this knowledge to less experienced project leaders. Such an attempt is called a *rational reconstruction* and the related type of research is *reconstruction research.* The literature on rational reconstruction is surprisingly meagre. The following section is partly based on Kamlah (1980) and Davia (1998).

A rational reconstruction presents a given problematic complex (the object of reconstruction) in a similar but more precise and more consistent formulation (the product of reconstruction) (Poser, 1980). The given problematic complex is typically intuitive, tacit knowledge. The simplest form of rational reconstruction is *explication*: the formulation of exact definitions for loosely defined concepts. Linguistic research is often reconstruction research (where one attempts to make explicit the grammatical rules that native speakers of a language know intuitively), as well as research in law (trying to reconstruct intuitive notions of right and wrong) and aspects of mathematics (*e.g.*, the axiomatic setup of probability as an attempt to formalise intuitive notions of probability).

Rational reconstructions could have a purely descriptive impetus. The emphasis is on reconstruction as 'again'-construction ('re-' as 'again'), *i.e.*, making the object 'more equal to itself' by extracting essential elements and reformulating and restructuring them. The main criteria for adequacy in this case are *clarity, exactness*, and *similarity to the original*.

One step further is a rational reconstruction with a prescriptive impetus. The emphasis is on 'new'-construction ('re-' as 'new'). The original material is taken as a starting point, but based on critical examination (on the basis of external formal criteria such as logic), it is corrected. Besides clarity and exactness, we have in this case the criterion of *consistency*, which replaces the criterion of similarity.

We could regard the BC as an attempt to reconstruct the know-how needed to conduct a quality improvement project. Its validation would amount to a verification of:

- similarity (To what extent does the BC correspond with the tacit knowledge of experienced project leaders?)
- exactness (To what extent do definitions and classifications give unambiguous demarcations of concepts?)
- clarity (How clearly organised is the exposition of the BC?).

Should we regard the BC as a reconstruction with a prescriptive impetus, we would compromise the similarity criterion to the favour of: consistency (to what extent is the BC free of internal contradictions?).

Although elements of this approach are important, this approach does not give us the whole picture, mostly because it makes the know-how of experienced project leaders the prime referee of the validity of the BC. This may be suitable for other examples of reconstruction research (linguistics, law), but prescriptions are a means to an end, and empirical records of the extent to which they attain their intended ends are perhaps even more important referees of their validity.

3.3 Grounding research

Grounding research – the third option that we consider – is an investigation into the *rationality* of prescriptions or, in general, of actions. Actions are called *rational* if they are criticisable and can be grounded (Habermas, 1981,p.25ff.). Rational actions embody certain presumed knowledge, and therefore imply a validity claim. For example, if a person performs a certain action with a specific purpose in mind, he implicitly claims the effectiveness of the chosen action in attaining the purpose. Or if a person makes a statement about certain matters of fact, he claims the truth of his statement. The rationality in these actions consists of their claimed effectiveness or truth. To ground an action is to show that these claims are warranted, *i.e.*, that the knowledge on which they are based is true. Different types of actions raise different validity claims ('effectiveness', 'truth'), and should, consequently, be grounded differently, depending on the precise manner in which the action relates to the knowledge that underpins it (Habermas, 1981,p.67). One of the reasons why the rationality of actions matters, is that their criticisability makes it possible to improve them. Thus, grounding is closely related to learning (Habermas, 1981,pp.38–39).

In order to ground the BC (as we have seen, a system of prescriptions), we have to formulate the validity claims that it makes, and next, verify that these claims are warranted. The basic form of a prescription is:

Given a certain situation, then take action X in order to attain a certain goal Y. (1)

The validity claim that a prescription makes is 'usefulness'. This claim is composed of two claims:

The goal Y is legitimate. (2)

Cause (action) X results in effect (goal) Y. (3)

In order to ground (*i.e.*, validate the usefulness of) a prescription of the form (1), one would have to validate the legitimacy of goal Y (*Value grounding*), and validate the explanatory argument (3). Argument (3) could be validated either by providing empirical evidence that confirms the stated X-Y relation (*Empirical grounding*), or by another statement or theory, which is valid and which implies (3) (*Theoretical grounding*). Moreover, one should bring the prescription in the form (1) (*Rational reconstruction*) and specify the situations in which it is applicable (*Specification of applicability*).

The analysis above was much influenced by a similar analysis by Lind and Goldkuhl (2002) who study the grounding of methods for business change. The analysis specifies the various aspects of a complete grounding study of the BC. Below, we elaborate on these aspects, thus establishing a research plan.

3.3.1 Rational reconstruction

The BC is formulated in unscientific language (ranging from imprecise and incoherent to meaningless and silly). Consider, as an example, the inconsistent demarcation of the phases Measure, Analyse, Improve, and Control[1] or the vague definition of a concept as CTQ (Harry, 1997,p.12.20). Before grounding of the BC can take place, the research should first focus on explication of its:

- concepts and classifications
- procedures
- application context.

Next, the admissibility of the BC should be tested, and when necessary the BC should be corrected. This means that it should be shown to what extent statements and principles that are part of the strategy are consistent.

3.3.2 Value grounding

Prescriptions are legitimatised by their goal. Are the BC's goal and its associated values valid? Sometimes it is stated that the goal of Six Sigma projects is to bring each process on the Six Sigma level of quality (3.4 ppm defects) (Harry, 1997,pp.2.11–18). From an economical point of view this claim seems in this general form untenable, and it is questionable whether the majority of Six Sigma projects really aim at this objective (let alone whether it would be possible to prove that such a low defect rate would have been attained, given the enormous sample sizes that would be required to do so).

Other descriptions of the goal of Six Sigma projects are described as quality improvement, breakthrough, variation reduction, defect reduction. In turn, these goals are legitimatised by concepts as *Costs of Poor Quality* (Breyfogle, 1999,Chap. 1). The adequacy of this paradigm should be studied, and alternative paradigms (*e.g.*, borrowed from economics and strategic management rather than quality management) should be explored.

3.3.3 Theoretical grounding

The effectiveness of prescriptions can be validated by explaining from (an external) theory why they work. For improvement strategies this is done in De Mast (2002), which explains the effectiveness of the BC by showing that it follows scientific method for empirical inquiry.

3.3.4 Empirical grounding

Empirical grounding takes the form of survey research, in which the effectiveness of the BC is estimated from empirical data, possibly as function of various factors. An example of the type of survey that is meant is Easton and Jarrell (1988), who study the effectiveness of TQM.

3.3.5 Specification of applicability

The analyses announced above should provide indications about the applicability of the BC. They should identify factors which affect the effectiveness of the BC, or which could even make it completely ineffective (an impossibility to collect measurements, to mention an example). However, this issue as well should be limited to methodological conditions (Organisational conditions that should be met in order to conduct an improvement project successfully should be studied elsewhere.).

3.4 Research plan

We can now state the definitive research outline. The appropriate steps for a scientific study of the validity and applicability of Six Sigma's BC would follow the scheme:

1 rational reconstruction (explication and precisation) of the BC

2 grounding of the BC (value grounding, theoretical grounding, empirical grounding)

3 identification of contexts where it can be applied

4 identification of conditions that affect the success of application.

4 Literature review

4.1 Objective and design

This section presents an inventory of scientific literature on Six Sigma, especially with the research plan described above in mind. We consider articles that have been published in four scientific journals in the field of industrial statistics:

1 *Quality Engineering* (QE)

2 *Quality and Reliability Engineering International* (QREI)

3 *Journal of Quality Technology* (JQT)

4 *International Journal of Quality and Reliability Management* (IJQRM).

In addition, two books were taken along in the overview: Harry (1997) and Breyfogle (1999). The objective of the inventory is to assess to what extent the four parts of the research plan (Section 3.4) are covered in literature. The next section gives an overview of the articles that were found. This overview is organised around the four parts of the research plan described in Section 3.4.

4.2 Overview of relevant papers

It was noted in Section 3.3 that Harry's (1997) exposition of the BC does not meet scientific standards of consistency and precision. Breyfogle's (1999) exposition has similar shortcomings, and we have not found better descriptions, thus underlining the observation that an explication or *rational reconstruction* of the BC is needed.

The issue of *value grounding* is addressed in literature by Harry (1997), who focuses on the 'hidden factory' model to validate Six Sigma goals (p.14.10). Defects have an effect on the amount of rework to be done, which in turn affects costs, cycle times, and required inventory levels (p.17.16). The BC can reduce these, Harry reasons (pp.2.12–13).

Somewhat more articulate accounts of Six Sigma in terms of organisational goals are given respectively by Wasserman and Lindland (1996) and Bisgaard and Freiesleben (2001). The former authors employ the cost-of-quality framework, which can be used to argue for the proliferation of Six Sigma initiatives. They adopt a financial point of view and show that there is an essential trade-off between the cost-of-control versus the cost-of-lack-of-control. The optimal quality level (in terms of conformance) is at a certain level, which shifts to a higher value as customer expectations rise. As a consequence (in view of ever increasing customer expectations) organisations are forced to provide higher and higher quality levels. This justifies the deployment of the BC.

Bisgaard and Freiesleben (2001) also show that defect elimination and prevention can create financial results (high return on investment). The conclusion is that "(1) quality improvement is an investment not a cost and (2) any financial benefit of improving operational efficiency, the stated goal of Six Sigma, goes directly to the bottom line and often provides an exceptionally high rate of return". Moreover, because reducing defects is an internal affair, it is on principle easier to reduce cost than to increase sales. The intent of Bisgaard and Freiesleben seems to give an illustration, rather than a scientific understanding of the validity of the goals of Six Sigma.

An integrated account of the functionality and purpose of Six Sigma seems to lack. All three accounts frame the benefits of Six Sigma in accountancy terms (costs) and focus on the BC as a method to improve *quality*. The costs paradigm seems valid, but is one-sided: the functionality of the BC should also be studied from perspectives such as business strategy, process innovation, the use of knowledge in organisations, and others. As for the limitation of the BC as an approach for quality improvement: many projects focus on cost reduction, cycle time reduction, or yield improvement. These are subsumed under *quality* by stretching the meaning of that term. This type of conceptual erosion is scientifically speaking undesirable.

Theoretical grounding of the BC has been done by De Mast (2002; 2003), who shows that the BC follows scientific method for empirical inquiry. The author also identifies a number of anomalies in the BC, where it deviates from standard research methodology for no apparent logical reason. The lack of emphasis of the iterative nature of empirical research, and the underexposure of the elaboration phase in the BC serve as examples.

The literature is also poor when it comes to *empirical grounding* of the BC. Hahn *et al*. (2000) mention three famous showcases of billion-dollar savings due to Six Sigma (Motorola, AlliedSignal, General Electric), but this is anecdotal evidence. An example of serious empirical grounding (*i.e.*, having a scientifically acceptable research design) of quality improvement methodologies is the research by Easton and Jarrell (1988). These authors have investigated the impact of TQM on financial performance. Although TQM is wider than Six Sigma and the BC in particular, their methodology may be useful for evaluation of the BC.

Hardly any attempt has been made to show in which situations, under what conditions, and for what purposes the application of the BC is successful. No systematic effort has been undertaken to pinpoint exactly where Six Sigma can be effectively applied, possibly because there is no agreement of what Six Sigma is, and the programme can therefore be stretched to fit the situation. Opinions about the conditions under which the BC applies diverge. Goh (2002a) claims that the BC does not apply to knowledge-based environments, such as scientific research. Others (Hahn *et al*., 2000) see tremendous opportunities for Six Sigma to be applied in virtually any context. Along the same lines Sanders and Hild (2000b) contend that Six Sigma is applicable to any business process: "The concepts of measuring process performance, making decisions via data, increasing efficiency, and improving quality are obviously much needed and logically applicable in the administrative and business areas of organisations." However, all these viewpoints are based on personal experience instead of systematic empirical research.

Apart from addressing the central questions of our research plan, literature focuses on other subjects as well. These articles can be classified according to their topic in:

- articles about tools: Goh (2002b), Goh and Xie (2003), Ribardo and Allen (2003)
- articles providing an overview about evolution, extensions, and the strategy of Six Sigma: Sanders and Hild (2000b), Sanders *et al*. (2000), Montgomery (2001), De Mast (2004)
- articles about implementation and deployment: Sanders and Hild (2000a)
- articles about training material and related issues: Hoerl (2001)
- case studies: Sanders and Hild (2001), Bayle *et al*. (2001), Rasis *et al*. (2002; 2003).

4.3 Conclusion

Generally speaking, one can say that the BC has not been grounded sufficiently in current literature: the questions of the research plan are not addressed in full or sometimes not at all. Specifically, we draw the following conclusions:

Conclusion 1 Expositions of the BC fall short in consistency and precision.

Conclusion 2 There have been some attempts at value and empirical grounding of the BC, but these attempts are insufficient from a scientific point of view. Legitimisation of the goals of application of the BC is too one-sidedly focused on costs. Empirical grounding relies solely on personal experiences of practitioners, not on serious empirical research.

Conclusion 3 Theoretical grounding of the BC has been done appropriately. The conclusion is that the BC largely follows standard research methodology. Directions for improvement have been identified.

Conclusion 4 Examination of literature on the BC and Six Sigma learns that most articles on Six Sigma focus on other issues than grounding of the BC. Instead they deal with issues such as implementation, case studies, training material, tools and the like. The intended audience of these articles is Six Sigma practitioners, not scientists.

5 Motivation for a grounding study of the BC

5.1 Why should a grounding study of the BC be carried out?

In the last 15 years Six Sigma has developed into a generally accepted standard for quality improvement in industry, and is slowly developing towards general application in the service industries as well. However, the programme is not well researched. There is an extensive literature on the subject, but this literature lacks the accuracy and critical attitude of scientific research (see the literature review in the previous section). The combination of these points implies that, although the world is in need of a standard that has a good grounding and a crystallised formulation, the current literature cannot provide this.

5.2 How does this research fit in the bigger picture of industrial statistics?

Industrial statistics could be described as "The discipline that develops quantitative methods for applied research in industry".

From reading the industrial statistical journals (such as *Technometrics*, *Journal of Quality Technology*, *Quality and Reliability Engineering International*, and *Quality Engineering*) one could get the impression that industrial statistics is a specialism within mathematics. Statistical inference is, however, certainly not a form of mathematical reasoning: in the latter, theorems are derived by deduction from axioms; in the former, conclusions are arrived at by inductive reasoning. Mathematics enters where statisticians study an empirical system by advancing a model for it (see, *e.g.*, Mayo, 1996,Chap. 5). The internal logic of the model (with all its standard machinery of reasoning, such as hypothesis testing and confidence interval estimation) is based on mathematical axioms and deductions. But the definition of the system under study is an empirical matter, not a mathematical one (*i.e.*, empirical reality is the guiding principle here, not mathematical axioms), and the translation of inferences for the model to conclusions about the empirical system requires extramathematical (inductive) reasoning. It follows that mathematics is only a modest part of industrial statistics and that research in industrial statistics should not be restricted to mathematical research (In fact, this holds for statistics in general, and even for probability: "Probability is no more a branch of mathematics than is physics, although it owes a great debt to mathematics for its formulation and development" Fine, 1988).

It is the strong conviction of the authors that industrial statistics should develop beyond research dominated by mathematics, and also beyond methodological research which lacks a sound scientific approach, but should extend to truly scientific research of methodologies.

6 Concluding remark

The exposition in this paper of a possible approach for a scientific study of Six Sigma's methodology is intended to stimulate academic interest in the programme. The research as outlined above will be carried out at the University of Amsterdam in the next three years. We are strongly convinced, however, that a study that covers as much ground as this one could greatly benefit from collaboration with other researchers. For this reason we wish to invite researchers willing to contribute to contact the authors.

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Note

1 For example, the descriptions of these phases in Harry (1997,pp.22.4–5) are not consistent with the steps that these phases are comprised of (p.22.2): the descriptions of the *Measure*, *Analyse*, and *Improve* phases suggest that Step 4 ('Establish Product Capability') should be listed under the *Measure* phase, and Step 6 ('Identify Variation Sources') under the *Improve* phase.