The Scientific Underpinning of Lean Six Sigma

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Publication date
2007

Published in
Proceedings of the 56-th Session of the International Statistical Institute, Lisbon, Portugal

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1. Introduction

Lean Six Sigma is a widely applied program for company wide quality improvement. It is the synthesis of Six Sigma and Lean. Six Sigma was developed by Motorola in the 1980s, but gained momentum after its adoption by General Electric in the mid 1990s. Lean is an outgrowth of the Toyota Production System. A few years ago Linderman, Schroeder, Zaheer and Choo (2002) remarked that: “While Six Sigma has made a big impact on industry, the academic community lags behind in understanding of Six Sigma”. In the last few years several members of the Institute for Business and Industrial Statistics of the University of Amsterdam (IBIS UvA) have tried to fill this gap, by carrying out some in depth research on the topic. In this paper we give an overview of the research on Lean Six Sigma which has been carried out by members of IBIS UvA. This institute supports quality and efficiency improvement initiatives based on its expertise in the field of statistical methodology. IBIS UvA has over 10 years of experience with Lean Six Sigma, and has supported Lean Six Sigma initiatives at General Electric Plastics, Sara Lee-Douwe Egberts, Paccar-DAF Trucks, Perlos, LG.Philips Displays, Philips Lighting, Getronics, TNT Mail Netherlands, Achmea Pensions, ABN AMRO Bank, Wolters Kluwer, Red Cross Hospital, Canisius Wilhelmina Hospital, Virga Jesse Hospital, and many more Dutch and international organizations.

The institute is owned by the University of Amsterdam, and promotes itself internationally as a center of expertise in Lean Six Sigma and industrial statistics (De Mast and Does, 2006). The members of the institute are frequent publishers in the international scientific literature as well as the professional literature. Members of the institute have authored books about Lean Six Sigma (De Mast, Does and De Koning, 2006) and Statistical Process Control (Does, Roes and Trip, 1999).

IBIS UvA sees the interaction between scientific research on the one hand, and the application of technology in business and industry on the other as its core.

- Research focuses on statistical methodology for quality and efficiency improvement, and on the business economic context of quality and efficiency improvement.
- Consultancy focuses on the support of Lean Six Sigma implementation programs, in which the institute plays the role of master black belt (project support, training, program support).

Currently, the staff of IBIS UvA consists of nine enthusiastic members. The advisors have had an extensive scientific education. Three of the staff members combine their activities at IBIS UvA with a professorship at the University of Amsterdam. Along with a broad scientific knowledge, advisors of IBIS UvA BV have an extensive experience in business.

2. Organizing quality improvement

Before turning to the scientific study of the *methodological* aspects of Lean Six Sigma, we first elucidate the organizational structure prescribed by the program. The key principle is that projects are run by people with intimate and detailed understanding of the process and problem at hand (see for an introduction the book of De

Mast, Does and De Koning, 2006). That implies that mostly projects are executed by people from the line organization, and not by staff personnel (let alone external consultants). The motivation is of course that line persons are aware of the treacherous details that are part of the problem, its solution, and that pose limitations on improvement directions. Moreover, since improvement actions ultimately are handed over to the line (to the employees, operators and process engineers), it is important that the solution is such that they can work with it, and that they accept it. Typically, a Lean Six Sigma project is run by a team consisting of:

- One or more Black Belts (BBs) and/or Green Belts (GBs), who are typically selected from middle management. They are thoroughly trained in becoming effective project leaders, and they work either full-time or at least a considerable part of their time on the project.
- Several Yellow Belts (YBs): persons that the BB or GB calls in as advisors, typically operators or employees who execute the process, but YBs could as well be technical specialists, marketing specialists, or whoever the BB or GB thinks could bring in relevant knowledge. On a limited number of occasions input from the YBs is requested, and they may be called upon to collect data.

The difference between a BB and a GB is interpreted differently in various organizations, and the precise role of a BB and a GB should be adapted to the situation in one's own organization. In some companies, a BB refers to project leaders who work full time on their project, whereas GBs work two or three days per week on their project. BBs then run the tougher projects. But a different approach is to have projects executed by a full-time BB from a staff department, assisted by one or two part-time GBs from the line.

The above implies that improvement projects are not run from a central staff department (such as quality assurance or troubleshooting). Rather, the idea is that GBs and BBs are dispersed over the organization. The danger of such a decentralized approach to improvement is that there is no integration of activities, and that efforts are wasted on issues that are not of strategic importance. For this reason, projects are selected and monitored by so-called Six Sigma champions. The champion is the project owner, in the sense that he is responsible for the process that the project aims to improve. Preferably, the champion is also the hierarchical superior of the BB or GB. Loosely said, the champion owns the problem, and hires the BB and GBs to solve it. Given his position in the company, the champion should be able to relate the project to the bigger picture of the company's strategy and other initiatives. During its execution, a project is reviewed several times by the champion, thus allowing him to adjust the direction that the BB or GB chooses. This control mechanism is intended to assure that the project remains focused on issues of critical importance to the company.

The structure just described has firm roots in the scientific literature about theory of the firm. Jensen (1998) discusses the merits of this organizational structure in dealing with quality improvement (albeit in the case of Total Quality Management).

3. Core elements of sound methodology

Part of theoretical grounding of Six Sigma may be found in De Mast and Bisgaard (2007). They show that several elements in Six Sigma's methodology constitute its sound basis in scientific methodology. In this section we give some highlights of their paper in the context of Lean Six Sigma.

Central to a scientific attitude towards process improvement is the idea that to control a system we have to understand how it works. Without understanding of the mechanics of a problem, we are likely just fighting symptoms and applying makeshift solutions. To understand a system means: to have a theory that relates the system's behavior to its causal factors. De Koning and De Mast (2007) draw the conclusion that "Six Sigma does not offer standard cures, but a method for gaining understanding of the causal mechanisms underlying a problem".

The next principle is that we have to define problems in a crystal clear, operational form before attempts at finding a solution are made. Targets and objectives are often formulated in abstract terminology: "to become a number one supplier", "to be best in class", "to become an empowered organization". Although such objectives are useful in stating an intention and providing a sense of direction, they are too vague to manage upon. Objectives should be translated into a tangible and measurable form. An objective is operationally defined if its formulation is so tangible, that one can determine precisely and unambiguously whether the objective is met. In Lean Six Sigma problems are translated into measurable quantities, called critical to quality characteristics (CTQs). A commonly used tool to go from a project definition to these specific and measurable CTQs is the CTQ flowdown (De Koning and De Mast, 2007). It aims to make explicit and structure the rationale underlying the project. Furthermore, it shows how CTQs relate to higher level concepts such as performance indicators and strategic focal points. Downward it shows how CTQs relate to measurements.

A third cornerstone of Lean Six Sigma's methodology is the emphasis on quantification. Customer satisfaction versus production costs, crime prevention versus privacy of citizens, pollution and noise nuisance of airports versus economic interests: most interesting problems are trade-off problems. The issue is not “either / or”, but “how much of one, and how much of the other?” If problems are not quantified, their trade-off nature is obscured, and people tend to treat them as either/or-problems (and frequently politicize them in addition).

The fourth principle indicates that before attempts are made to solve the problem, a data-based diagnosis is needed. In Lean Six Sigma this takes the form of a process capability study. This shows the nature and size of the problem. The nature of the problem guides the direction of the improvement actions, the magnitude of the problem facilitates prioritization. The importance of prioritization cannot be overemphasized. The saying has it that “every ounce helps”, but this proverbial wisdom does not work in business. With unlimited time and resources one could bother about ounces, but in reality one must focus on the strategically important issues. Or in Lean Six Sigma’s terminology: each minute spent on the trivial many issues is a minute lost; it is the vital few issues that determine the success of a project. Without data-based diagnosis improvement actions are likely to be wasted on many trivialities, not on the few drivers of performance.

A final element of Lean Six Sigma is its emphasis on data-based testing of ideas and improvement actions to reality. In a world where no-one is likely to have sufficient knowledge to be consistently right the first time, feedback is crucial. One should experimentally verify one’s ideas for two reasons. In the first place, to get rid of misconceptions, misjudgments and myths. And secondly (and equally important), to fine-tune a coarsely developed idea to the specifics and complications of the real life situation. Ideas that are not tested before they are implemented are often either misconceived, or appear to be based on a wrong notion of proportions and priorities, or fail because of the many ignored growing pains.

The principles outlined above were put in an operational form in the form of the DMAIC roadmap. It employs five phases: Define (D), Measure (M), Analyse (A), Improve (I) and Control (C). The roadmap guides BBs and GBs through their projects, helps them ask the right questions, shows them when certain tools and techniques can be used, and forces them to organize their findings in a structured manner. The five phases are briefly characterized as follows:

1. Define: Select project and BB or GB.
2. Measure: Make the problem quantifiable and measurable.
3. Analyze: Analyze the current situation and make a diagnosis.
4. Improve: Develop and implement improvement actions.
5. Control: Adjust the quality control system and close the project.

Each of these phases is discussed in depth in De Mast, Does and De Koning (2006). Each of the MAIC phases is broken down in three steps. For each step a list of end terms is defined as well as a set of techniques that are typically used to achieve them. BBs and GBs report the progress of their projects following these steps, which makes it easy for program management to track progress.

Hence Lean Six Sigma elevates problem-solving and quality improvement to a more professional level by providing a method that follow scientific method and by training BBs and GBs in an attitude that can be described as scientific. Improvement actions are not based on perception and anecdotal evidence. But neither are they based on the notion of the omniscient specialist who, sitting behind his desk, derives a remedy by making clever deductions from his expert knowledge. The attitude that Lean Six Sigma represents, is an adventurous and open-minded eagerness to go out to the process under study and learn from it, and the willingness to correct one’s own misconceptions on the basis of experimental results and empirical feedback. That is in a nutshell the tenor of Lean Six Sigma’s methodology.

4. How to research a methodology?

Scientific investigation of statistical improvement programs, such as the Lean Six Sigma program, is needed and should provide a better understanding and suggest directions for improvement. Such an investigation confronts the scientist, however, with the problem that Lean Six Sigma, like other statistical improvement programs, has many aspects that belong to different disciplines in science, such as statistics, methodology, management science, economics and quality engineering. Many of these aspects can be studied using standard research approaches. However, there will be aspects for which the scientist cannot fall back on a standard approach, but is forced to work-out a research design himself.

In this section we will work-out a scientifically sound approach for studying the validity and applicability of Lean Six Sigma’s DMAIC method for improvement projects. Note that we only take into consideration the program’s methodological aspects, which includes its method, tools, and concepts, but excludes issues like Lean Six Sigma’s organization, training, project selection, etc. We consider several research methodologies, whereupon a grounding research approach is developed. A comparison of the results of a literature review and the proposed research approach learns that current literature on the methodological aspects of Lean Six Sigma does not meet scientific standards of precision and consistency (De Koning and De Mast, 2005).

An important aspect of Lean Six Sigma's method is that it guides project leaders through a quality improvement project. It can therefore be characterized as a system of prescriptions: guidelines that tell a project leader what to do in order to reach a certain goal. One could consider to study the Lean Six Sigma's method following the approach of empirical research. In that case prescriptions (or rather, their application and the outcome of their application) are regarded as empirical phenomena. Measuring the success of their application, one could single out the successful elements of Lean Six Sigma's methodology from the less successful. Although the study of records of past uses is an important element of the approach that envisaged, it is not sufficient. Merely recording which prescriptions correlate with successful applications and which do not, gives no explanation of the way Lean Six Sigma's methodology works.

In order to gain insight in how successful prescriptions work, we must understand the internal logic of Lean Six Sigma's methodology. The Lean Six Sigma method is formulated in unscientific language (ranging from imprecise and incoherent to meaningless and silly), so the efforts should first focus on explication ("rational reconstruction"). The second step is aimed at understanding the internal logic of the Lean Six Sigma method. Thus, the research design contains the following elements:

- *Rational reconstruction* of the methodological aspects of the Lean Six Sigma program.
- *Grounding* (=validation) of the methodological aspects of the Lean Six Sigma program.

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). 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 set-up of probability as an attempt to formalize 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 Lean Six Sigma method as an attempt to reconstruct the know-how needed to conduct a quality improvement project. A rational reconstruction of the DMAIC methodology may be found in De Koning and De Mast (2006).

Grounding research is an investigation into the rationality of prescriptions, or in general of actions. Actions are called rational if they can be criticized and can be grounded. 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. One of the reasons why the rationality of actions matters, is that their criticizability makes it possible to improve them. Thus, grounding is closely related to learning.

In order to ground Lean Six Sigma's methodology (as we have already noted, 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:

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

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

(2) The goal Y is legitimate;

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

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). Finally, one should specify the situations in which Lean Six Sigma is applicable. In the paper of De Koning and De Mast (2005) these grounding aspects are discussed for the Six Sigma program.

5. Recent new applications of the Lean Six Sigma program

In this last section we deal with the question under what conditions and in what branches is Lean Six Sigma applicable. An important observation is that any organization, be it a business enterprise or a not-for-profit organization, could be conceived as a collection of routine operations. Manufacturing, sales, back-office processes, and nursing are all functions performed in a routine manner. Lean Six Sigma projects are about the improvement of these routine operations, seeking to make them more effective and more efficient, striving for processes that run like clockwork. Many of the routine operations suffer from recurring problems and crises. Line management and personnel are usually over-occupied keeping things running. Dealing with problems typically takes the form of fire fighting, and quick and dirty solutions are applied before rushing off to the next crisis. Recurring problems make good Lean Six Sigma projects. Lean Six Sigma brings understanding of the root causes of the problem, and provides a definitive and optimal solution. Even if a process does not suffer from severe problems, there is a lot to gain from periodical process overhaul. Processes evolve over time, and typically they grow in the direction of more complexity, more malfunctions plus makeshift solutions, and more obsolete or redundant work. Moreover, the staffing is usually not based on calculation, but has historically grown. Lean Six Sigma projects optimize processes, eliminate waste, and provide a quantitative basis for staffing and line balancing.

Besides tackling internal problems, Lean Six Sigma projects are deployed to attack issues perceived by customers as problematic. Customer feedback shows which aspects of a business are perceived as substandard, but they can also point to new potential business. Projects tackle dissatisfiers, but can also develop or enhance latent opportunities for growth.

The improvement of routine operations is what Lean Six Sigma projects do, and in fact, Lean Six Sigma provides a management structure and methodology that turn systematic improvement of routine operations into a routine operation itself. Traditionally, Lean Six Sigma projects have been mainly targeted at improvement of manufacturing processes and back-office processes in the service industry. But sales, accounting, a physician's consulting hours are routine processes just as a manufacturing process, and Lean Six Sigma projects are increasingly deployed in improving their quality and efficiency as well.

The manufacturing industry has invested in the systematic exploration of opportunities for quality improvement, cost reduction and efficiency improvement for many years. Hence this industry has used Lean Six Sigma already for many years. However, there are sectors which are lagging behind such as Healthcare and Financial Services. Recently, IBIS UvA has implemented Lean Six Sigma in several hospitals and financial service institutions. It is gratifying to note that the application of Lean Six Sigma in these sectors generates a lot of interesting research questions. For example: Is it possible to standardize Lean Six Sigma projects in healthcare respectively in financial services?; What is the best way to implement Lean Six Sigma in healthcare respectively financial services?; Are there interesting case studies from these areas?

Healthcare, as any other service operation, requires systematic innovation efforts to remain competitive, cost efficient and up to date. Some operational inefficiencies are associated with the direct medical service delivery process. Others are associated with the administrative, logistical and operational side of the healthcare delivery system. Both areas can benefit from systematic process innovation activities.

It would not be a surprise if some object to the notion of industrialized healthcare delivery. Industrialization is essentially a conversion of artisan methods to more efficient, cost effective, streamlined systems for the delivery of products or services. However, healthcare is not a business like other. There are multiple decision makers, and conflicting goals and incentives. Take for instance a hospital: doctors are responsible for the cure; the nursing is responsible for the care; the patient (client) is part of the process; management has in general no control over the doctors. Nevertheless, Lean Six Sigma has recently also been applied in the healthcare sector. We have published several papers on these subjects. In Van den Heuvel, Does and Vermaat (2004) we present several case studies. In Van den Heuvel, Does and Bisgaard (2005) and Van den Heuvel, Does, Bogers and Berg (2006) the way to implement Six Sigma in a hospital is explained. Van den Heuvel, Bogers et al. report the results of the implementation over a period of five years. In De Koning, Verver et al. (2006) and Van den Heuvel, Does and De Koning (2006) the synthesis of Lean with Six Sigma in a hospital is described. In Does, Vermaat, et al. (2006) the generic project structure in healthcare is discussed.

Financial services institutions face increasing competition primarily because of globalization. Companies have to compete with domestic competitors as well as with best-in-class firms in a global context. Moreover, competitors from abroad usually play the strategy game according to different rules, making it harder to respond effectively. Thus to compete it is imperative to improve operational efficiency and effectiveness. Improving operational efficiency and effectiveness include quality improvement, cycle time reduction, productivity improvement, waste reduction and elimination of rework. Financial services companies need to eliminate operational inefficiencies, not just to gain competitive advantage, but even more fundamentally, to avoid competitive disadvantages and to stay in business (De Mast, 2006).

Operational inefficiency is typically associated with the direct financial services delivery process. However, the administrative, logistical and operational side of the financial services delivery system may also be ripe for improvement. Indeed all areas can benefit from systematic process innovations (Bisgaard and De Mast, 2006). We sometimes cling to pre-industrial notions about what service is and how it should be delivered. In fact, the type of innovations that have produced significant leaps in efficiency in the industrial environment have so far not been sufficiently applied to reduce inefficiencies in the financial services sector, or many other service sectors for that matter. We are involved in the implementation of Lean Six Sigma in financial services since 2000. We have published our findings in financial services in De Mast, Does and De Koning (2006), Does and De Koning (2006), De Koning, Does and Bisgaard (2007), and De Koning, De Mast, Does, Vermaat and Simons (2007).

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ABSTRACT

The twentieth century saw an incredible development of professional organizations. The impact of technological advances is obvious, but besides these, innovations in management structures and methods have resulted in the highly productive organizations of today. When the race for outperforming competitors on quality and efficiency gained momentum, companies started to copy each other's best practices. Consultants and management gurus quickly jumped in and started giving names to these best practices: total quality management, just-in-time, business process reengineering, statistical process control, quality circles, lean manufacturing, continuous improvement, et cetera. Out of these methods, principles and approaches time has singled out the ones that really have added value. And while most approaches have been presented as panaceas at one time or another, time has shown that they are in fact complementary.

Lean Six Sigma is not revolutionary. It is built on principles and methods that have proven themselves over the twentieth century. It has incorporated the most effective approaches and integrated them into a full program. It offers a management structure for organizing continuous improvement of routine tasks, such as manufacturing, service delivery, accounting, nursing, sales, and other work that is done routinely. Further, it offers a method and tools for carrying out improvement projects effectively. In an economy which is determined more and more by dynamics than by static advantages, continuous improvement of routine tasks is a crucial driver of competitiveness.

Lean Six Sigma builds on field-tested and proven principles that have been developed in quality engineering, management and industrial statistics over the twentieth century. We show in this paper that Lean Six Sigma's method has a sound basis in science, thus aiming to provide a case for Lean Six Sigma based on its core principles, rather than rhetoric. Furthermore, we give some insight in recent applications of Lean Six Sigma in healthcare and financial services.