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A methodological comparison of three strategies for quality improvement

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Abstract *Quality improvement is understood by Juran to be the systematic pursuit of improvement opportunities in production processes. Several methodologies are proposed in literature for quality improvement projects. Three of these methodologies – Taguchi's methods, the Shainin system and the Six Sigma programme – are compared. The comparison is facilitated by a methodological framework for quality improvement. The methodological weaknesses and strong points of each strategy are highlighted. The analysis shows that the Shainin system focuses mainly on the identification of the root cause of problems. Both Taguchi's methods and the Six Sigma programme exploit statistical modelling techniques. The Six Sigma programme is the most complete strategy of the three.*

Introduction

According to Juran (1989) the activities in companies that assure quality can be grouped in three processes:

(1) quality planning;

(2) quality control; and

(3) quality improvement.

In this paper, I focus on the last process, quality improvement. It consists of the systematic and proactive pursuit of improvement opportunities in production processes to increase the quality to unprecedented levels ("breakthrough"). Typically, quality improvement activities are conducted in projects. Its proactive and project-wise nature distinguish quality improvement from quality control, which is an online process that is reactive in nature. Compare as well Ishikawa (1990, p. 201) and Taguchi's (1986) distinction between online and offline quality control.

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With the purpose of guiding an experimenter in conducting a quality improvement project several strategies have been proposed. I define a quality improvement strategy to be:

> . . . a coherent series of concepts, steps (phases), methodological rules and tools, that guide a quality professional in bringing the quality of a process or product to unprecedented levels.

Traditionally, statistical methods have played an important role in quality improvement (as well as in quality control). The field of industrial statistics has yielded a number of methodologies for quality improvement. Improvement strategies based on statistical methodology typically follow the pattern of empirical inquiry:

(1) They try to identify improvement opportunities by discovering (causal) relations in the process between quality characteristics and influence factors.

(2) Conjectured relations are tested to empirical data before they are accepted as true (De Mast, 2002).

I shall call improvement strategies that comply with the two points above statistical improvement strategies.

In the literature on industrial statistics three statistical improvement strategies have received a lot of attention, namely Taguchi's methods, the Shainin system and the Six Sigma programme (see, for example, Nair, 1992; Steiner *et al.*, 2002; Hahn *et al.*, 1999). These strategies are different from each other to some extent (in terms of tools, terminology and approach) but also have many similarities. It is the purpose of this article to make a comparison among these strategies on a number of methodological themes. These themes are borrowed from a methodological framework for statistical improvement strategies. The comparison helps practitioners in assessing the merits of each strategy and thus in making a better motivated choice among them. For researchers in the areas of industrial statistics and quality management the comparison assists in positioning the strategies in relation to each other. Furthermore, a systematic discussion of the differences among various strategies provides relevant information for attempts to improve current strategies or develop new approaches.

Unlike other comparison papers (e.g. Ledolter and Swersey, 1997; Vining and Meyers, 1990; De Mast *et al.*, 2000) this article focuses on methodological differences instead of differences in tools and techniques. Differences in organizational structure or implementation strategies are not studied in this article.

Below, I expound the followed research methodology and I introduce the three selected strategies. Thereupon, the elements of the methodological framework, which facilitates the comparison, are briefly introduced. The comparison itself is followed by a discussion in which the strong points and weaknesses of each strategies are highlighted. The conclusions are summarized.

Research methodology

In the last 15 years, the literature on industrial statistics (for example, journals such as *Technometrics, Quality Engineering*, the *Journal of Quality Technology* and *Quality and Reliability Engineering International*) is dominated by a few approaches to quality improvement which depend on statistical methods. Especially statistical process control (SPC), Taguchi's method, response surface methodology (RSM) and improvement by experimentation, total quality management (TQM) and – in recent years – the Six Sigma programme are the subject of a lot of discussion papers, case studies and papers on application issues. Less frequently discussed approaches are quality function deployment (QFD), automatic process control (APC) and the Shainin system.

Comparing these approaches to the given definition of statistical improvement strategies, I found Taguchi's methods, the Shainin system and Six Sigma's Breakthrough Cookbook to comply most closely. SPC is an approach for quality control, rather than quality improvement. RSM covers only part of the work in a quality improvement project. TQM is a philosophy or programme, rather than a step-wise strategy. QFD depends more on systematisation of available knowledge than on empirical investigation to discover causal relations, and also APC is not based on the discovery of causal relations.

The study of improvement strategies as prescriptions for quality improvement projects can be seen as reconstruction research. This type of research studies systems of rules and seeks to formulate a rational reconstruction of these rules. A rational reconstruction presents a given complex system – such as a system of rules – in a similar but more precise and more consistent formulation. Rational reconstructions can have a purely descriptive impetus, but often have a prescriptive objective as well. De Mast (2002) presents a reconstruction study of statistical improvement strategies, resulting in a methodological framework. The elements of this framework serve as the themes that are used to compare the selected improvement strategies. By comparing the corresponding elements in the selected strategies, the differences are revealed.

The strategies

Taguchi's methods

In the 1980s interest in quality improvement among quality engineers and statisticians in the West grew substantially. Most emblematic among the originators of this interest is the Japanese engineer Genichi Taguchi. Although he had been working on his quality improvement ideas since the 1950s, his methods were virtually unkown outside of Japan until the 1980s. His techniques and vocabulary are heavily based on his engineering background, and they differ to some extent from the statistical techniques and vocabulary that are used in traditional quality improvement.

Taguchi discerns between online and offline quality control. Offline quality control concerns the design (or re-design) of products and processes, and includes the stages system design, parameter design and tolerance design (Taguchi, 1986, pp. 75-79; see also Kackar, 1985). Restricted to operational production processes Taguchi's offline quality control conforms to my definition of quality improvement.

Taguchi invented and promoted various new concepts, such as a quadratic loss function (Taguchi, 1986, p. 15). These concepts represent a view on quality in which variation plays a dominant role. This view on quality is generally accepted (Nair, 1992). Furthermore, Taguchi introduced an alternative experimentation methodology (using orthogonal arrays; see Ross, 1988). The adequacy of this methodology has been the subject of much debate among statisticians (Nair, 1992), though it is popular in engineering (Jugulum and Dichter, 2001). As an operationalisation of Taguchi's methodologies and concepts I consider a stepwise strategy described by Ross (1988). This approach is built around Taguchi's quantitative experimentation methodology.

Taguchi emphasises the importance of variation reduction in quality improvement. Based on the results of an experiment, settings for the control variables are chosen such that the process is made robust against variation in the nuisance variables. Next, the process mean is brought on target by manipulation of control variables that affect the mean but not the variation. Finally, tolerance design is exploited if needed to accomplish a further reduction in variation.

Shainin system

Dorian Shainin put several techniques – both known and newly invented – in a coherent stepwise strategy for problem solving in a manufacturing environment. This strategy is called the Shainin system, or statistical engineering. The system is described in various papers (Shainin, P., 1993; Shainin, R., 1993). Part of the strategy is promoted by Bhote (1991). Starting from a problem in the output of a process, the objective of the strategy is to select the one, two or three dominant causes of variation (called the Red X, Pink X and Pale Pink X, respectively) from all possible causes. This is achieved by a "homing in" method: using statistical analysis tools, the classes of causes in which the important causes are likely to be found are selected, thus zooming in on the Red X. Once the Red X is identified, either an irreversible corrective action is taken, or the tolerances on the Red X are tightened and controlled.

The Shainin system is built around a set of tools that are plainly understood and easily applied, hereby refraining from more advanced techniques. The theory is clarified using a clear vocabulary (featuring concepts as "Red X" and "homing in strategy"). Because of its simplicity and the integration of tools the system appeals to persons with a technical background and limited knowledge of statistics.

The Six Sigma programme
Six Sigma is a philosophy for company-wide quality improvement. It was developed by Motorola and popularised by General Electric. Several variants are current (compare, for example, the approaches described in Harry, 1997; Breyfogle, 1999; and Pyzdek, 2001). For the strategical and methodological aspects I discuss the variant as presented by Harry (1997), which was introduced at General Electric. For a description of the tools and techniques I consulted Breyfogle (1999).

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:

(1) measure;
(2) analyze;
(3) improve; and
(4) control.

The breakthrough cookbook is part of an embracing strategy – the outer MAIC-loop – which comprises the strategical co-ordination of improvement projects (Harry, 1997, pp. 21.21-22). The 12-step inner MAIC-loop is studied here as statistical improvement strategy.

The Six Sigma programme is a complete programme for company-wide quality improvement, encompassing methods for analysing the customer's demands and for selecting the problems having the highest priority. It features virtually all relevant tools and techniques that have been developed in industrial statistics, from control charting to design of experiments, and from robust design to tolerance design. The programme is set up in a way that it can be applied to a range of areas, from manufacturing to services. The implementation and application in the organisation is co-ordinated by "champions" and "Master Black Belts". Projects are conducted by "Black Belts" and "Green Belts", who are selected from middle management.

The methodological framework
Below, I discuss the elements E1 through E7 of a methodological framework for quality improvement strategies. For a more elaborate discussion and references, see De Mast (2002).

E1. Explanatory networks and their structure

Statistical improvement strategies seek to relate a quality phenomenon to the factors that cause it. Thus, the result of a quality improvement project has the form of a network that specifies the relations between factors in the process and the quality characteristic under study. Critical to quality (CTQs) are those quality characteristics that are the subject of the improvement project (in the sense that the quality problem can be translated in this form: one or a few CTQs do not meet their requirements). The factors that causally affect the CTQs are the influence factors. The explanatory network provides an explanation of the quality problem under study by specifying how the CTQs are affected by the influence factors. Improvement actions are derived from this explanatory network.

E2. Types of influence factors

Based on the role they play in an improvement project, influence factors could be distinguished in three categories:

(1) *Control variables*: continuous, discrete or even binary variables which are the experimenter's instrument to manipulate the CTQ. This implies that it is possible and feasible to set a control variable to a desired value.

(2) *Nuisance variables*: continuous, discrete or binary variables which are sources of unwanted variation that have to be eliminated or compensated for. It is not necessarily impossible for the experimenter to exert influence on their value, but especially during production it is either not feasible or unwanted to control their value.

(3) *Disturbances*: events that have an undesired consequence for the CTQ.

E3. Phases in improvement projects

The activities in improvement projects can be grouped in five phases:

(1) *Operationalisation*: operational definition of the problem.

(2) *Exploration*: identification of potential influence factors.

(3) *Elaboration*: ordering and explicitation of potential influence factors.

(4) *Confirmation*: experimental confirmation of the effects of influence factors.

(5) *Conclusion*: exploit discovered relations to define improvement actions and update quality control system.

The phases are based on the hypothetico-deductive method from philosophy of science, especially in the form of Dewey (1997). The core is formed by the exploration phase, in which potential influence factors are identified, the confirmation phase, in which the effects of the potential influence factors are experimentally verified, and the conclusion phase, in which the discovered relations between influence factors and CTQs are exploited to arrive at improvement actions. In the operationalisation phase the experimenter makes the problem under study operational. In the elaboration phase the identified potential influence factors are defined operationally. In De Mast (2002) the relationship between these phases and Box's (1999) inductive-deductive model and the PDCA cycle (Joiner, 1994) is explicated.

E4. Rules for the operational definition of the problem

In the operationalisation phase the experimenter makes his problem definition operational. This means that:

- The CTQ is associated with a (reliable) measurement procedure.
- The demands on the CTQ are stated (in terms of the defined measurement scale).
- The current magnitude of the problem is assessed.
- It is specified when the problem is considered solved.
- The population (i.e. the process) that is considered is specified.

E5. Heuristics for the discovery of potential influence factors

In the exploration phase the experimenter identifies factors that might affect the CTQ. For this purpose, he can study empirical data, systematise convictions that involved persons have, or consult accepted technical knowledge. The activities in this phase are not methodical, but literature provides heuristics that make these activities more effective.

- *Zooming-in strategy*: the space of possible influence factors is subdivided in classes (e.g. classes of types of variation). Identifying characteristical behaviour of the CTQ the experimenter eliminates entire classes of influence factors.
- *Thinking in standard categories*: influence factors could be searched in standard categories, such as man, machine, material, method, measurement and environment.
- *Assignable causes in data*: the experimenter searches for patterns in data, thus identifying potential influence factors.
- *Thinking in analogies*: influence factors that play a role in comparable problems could be translated to the problem at hand.

E6. Iterative nature of improvement projects

Inquiry means learning, and learning means that the experimenter starts out with incomplete knowledge and has to make assumptions. The learning process consists of refining and adjusting one's assumptions on the basis of confrontations with empirical evidence. Effective improvement projects exploit this interaction between assumptions and observations.

E7. Improvement patterns

On arriving in the conclusion phase, the experimenter has discovered and modelled relations between influence factors and CTQs. Based on these relations improvement actions are defined. These actions follow standard patterns:

- *Adjustment of the mean*: one or more control variables are adjusted to bring the CTQ's mean closer to its desired value.
- *Robust design*: one or more control variables are adjusted to make the process less sensitive to sources of variation such as nuisance variables.
- *Tolerance design*: the variation in a nuisance variable is reduced or eliminated.
- *Feedforward control*: a control variable is continuously adjusted to compensate for the variation of a nuisance variable.
- *Feedback control*: a control variable is continuously adjusted to compensate for unexplained drifts in the process.
- *Mistake proofing*: the occurrence of disturbances is prevented or their effect on the CTQ reduced.

The comparison

In this section I list the elements E1 through E7 of the methodological framework and compare the corresponding elements in the three strategies under study.

E1. Explanatory networks and their structure

E2. Types of influence factors

Table I gives an overview of the corresponding concepts in the discussed strategies. In the Shainin system, a specific quality characteristic that is important to the customer is called Green Y. For its influence factors – the "causes" or Xs – Shainin stresses the Pareto principle, which singles out the vital few causes (the Red X, Pink X, Pale Pink X, etc.) from the trivial many (Shainin, R., 1993). Shainin presents no distinction of causes which is comparable to E2.

Framework	Shainin	Taguchi	Six Sigma
CTQ	Green Y	Signal-to-noise ratio	Critical to quality, delivery or cost (CTQ, CTD, CTC)
Influence factor	Cause, X	Factor	Cause, X, leverage variable, source of variation
Control variable		Control factor	Controllable factor
Nuisance variable		Noise factor	Uncontrollable factor
Disturbance			

Table I. Comparison of strategies on E1 and E2

Projects following Taguchi's approach focus on the loss of poor quality, rather than on a quality characteristic. As a consequence, Taguchi's methodology does not offer an equivalent for the concept CTQ. Experiments and analyses focus on the loss function *L(y)*, which represents the monetary loss that an arbitrary customer is likely to suffer as a function of a quality characteristic *y*. Taguchi (1986, p. 15) motivates that *L(y)* can be approximated by a quadratic function having a minimum in *t*, the target value of *y*. The loss function is estimated by a series of performance metrics called "signal-to-noise ratios" (see León *et al.*, 1987). These metrics are taken as the responses in experimentation. The distinction between control variables ("control factors" in Taguchi's terminology) and nuisance variables ("noise factors") plays an important role in Taguchi's parameter design.

In the Six Sigma programme, the needs of the customer are translated into critical-to-satisfaction (CTS) characteristics. These are related to characteristics which are critical to quality, delivery or cost (CTQ, CTD, CTC) (Harry, 1997, p. 12.20). Influence factors are referred to under a variety of names, such as causes, Xs, leverage variables and sources of variation. Breyfogle (1999) introduces the terms key process output variable (KPOV) and key process input variable (KPIV) for CTQ and influence factor. Copying Taguchi's approach to parameter design, Breyfogle (1999, ch. 32) introduces the distinction between control and nuisance variables ("controllable" and "uncontrollable factors" in his terminology). Disturbances are not explicitly distinguished in either Taguchi's methodology or the Six Sigma programme.

E3. Phases in improvement projects

Table II compares the proposed phases and their order. The steps listed under the Shainin System were extracted from Shainin, R. (1993, figure 2). Taking the 16 "steps in experimentation" listed in Ross (1988, pp. 203-205) to represent Taguchi's step plan, I notice a strong emphasis on the experimentation phases elaboration and confirmation.

The Six Sigma programme groups its 12 steps in four phases (Harry, 1997, pp. 21.18-19):

(1) *Measurement*: a product related critical-to-quality (CTQ) characteristic is targeted and its performance on the "sigma scale" of quality defined.

(2) *Analysis*: the principal sources of variation in the CTQ are identified.

(3) *Improvement*: the "vital few" variables which govern the CTQ's performance are surfaced and with this knowledge operating limits for the leverage variables can be established.

(4) *Control*: a control scheme is identified and deployed for the vital few variables.

These descriptions match, to a large extent, the functions of the phases operationalisation, exploration, confirmation and conclusion respectively.

Table II. Comparison of strategies on E3

Framework	Shainin	Taguchi	Six Sigma
Operationalisation	1. Define the project 2. Establish effective measuring system	1. State the problem to be solved 2. Determine the objective of the experiment: identify the performance metric identify the level of performance when the experiment is complete 3. Determine the measurement method(s)	1. Select the CTQ characteristic 2. Define performance standards 3. Validate measurement system 4. Establish product capability 5. Define performance objectives
Exploration	3. Generate clues	4. Identify factors which are believed to influence the performance characteristic(s)	6. Identify variation sources
Elaboration	4. List suspect variables	5. Separate factors into control and noise factors 6. Determine the number of levels and values for all factors 7. Identify control factors that may interact	
Confirmation	5. Statistically designed experiment	8. Draw the required linear graph 9. Select orthogonal arrays 10. Assign factors and interactions to columns 11. Conduct the experiment 12. Analyze the data 13. Interpret the results	7. Screen potential causes 8. Discover variable relationships
Conclusion	6. Return to 3 if Red X not found 7. Optimize interaction 8. Realistic tolerances 9. Irreversible corrective action 10. Statistical process control 11. Monitor results	14. Select optimum levels of most influential control factors and predict expected results 15. Run a confirmation experiment 16. Return to step 4 if ojective is not met	9. Establish operating tolerance 10. Validate measurement system (Xs) 11. Determine process capability 12. Implement process controls

However, the division of the 12 steps of the breakthrough cookbook over Harry's four phases deviates from the grouping in Table II, in that steps 4 and 5 are grouped under analysis, and step 9. under improvement. This seems dictated more by the desire to have three steps in each phase than by methodological arguments.

The elaboration phase cannot be clearly distinguished in the discussed strategies. In Taguchi's methodology no clear delimitation between the elaboration and the confirmation phase could be found. The Six Sigma programme does not list explicitly steps in which potential influence factors are organised, defined operationally, and the possibilities for the experimental verification of their effect studied.

E4. Rules for the operational definition of the problem

Six Sigma pays adequate attention to the operational definition of CTQs and the problem under study. CTQs are made operational in the measurement phase. An opportunity for nonconformance requires (Harry, 1997, pp. 12.9-10):

- *A characteristic*: the attribute, trait, property or quality to be measured.
- *A scale*: the relative basis for measuring a characteristic.
- *A standard*: the criterion state or condition specifying nonconformance.
- *A density*: the empirical distribution of the observations made on this characteristic.

The objective of the project – in terms of the chosen metric – is stated in step 5. of the breakthrough cookbook. These demands conform closely to the requirements that were stated in the methodological framework.

In Taguchi's methodology the focus is on the selection of the relevant signal-to-noise ratio, and less on the precise definition of the problem in the form of a measurable characteristic. The current performance of the process is not assessed, and as a consequence, there is no check that the selected problem and the translation into a performance metric are suitable. In the literature on the Shainin System I could not find elaborate statements about operational definitions of CTQs or the problem. This is a serious shortcoming.

E5. Heuristics for the discovery of potential influence factors

The Shainin system advocates the zooming-in strategy explicitly and provides a system of techniques which makes use of it (multi-vari charts, paired comparisons etc.) (see Bhote, 1991, chs. 6 and 8). Shainin rejects qualitative investigation for the work in the exploration phase, to the favour of quantitative inductive techniques:

> There is no place for subjective methods such as brainstorming or fish bone diagrams in serious technical problem solving' (Shainin, P. 1993).

In Taguchi's methods the identification of possible influence factors is limited to the basic tools of brainstorming, flowcharting and fishbone charting (Ross, 1988, section 3-4-1). In the Six Sigma programme a vast collection of tools and techniques is suggested (flowcharting, brainstorming, cause and effect diagrams, run charts, control charts, multi-vari charts, ect.) (see, e.g. Breyfogle, 1999, chs. 4, 5 and 15). However, these techniques are not placed in a strategy, heuristic, or other method.

E6. Iterative nature of improvement projects

Taguchi has been criticised for not recognising the sequential and iterative nature of learning. In Nair (1992), for instance, Box criticises Taguchi for being "{. . .} intended only to pick the 'optimum' factor combination from a *one-shot experiment*" (emphasis is mine). In the same article, Myers and Vining express a similar criticism. The Shainin System and the Six Sigma programme as well do not emphasise the iterative nature of learning. The notions of learning from error and that hypotheses and even the problem definition can be modified when insight advances are completely absent.

E7. Improvement patterns

The Shainin system focuses on problem solving and tolerance design. It provides no effective tools for adjustment of the mean, robust design, or other improvement patterns. Robust design (in combination with adjustment of the mean) was introduced by Taguchi under the name "parameter design". First, dispersion – as measured by a signal-to-noise ratio – should be minimised, and thereupon the process mean should be brought on target. Only if robust design is not adequate should tolerance design be applied.

Six Sigma centers around experimentation. Among the suggested improvement actions are adjustment of the mean, robust design (Breyfogle, 1999, ch. 32), feedback control (briefly discussed in Breyfogle, 1999, ch. 36), mistake proofing (Breyfogle, 1999, ch. 38), and tolerance design (step 9 in the breakthrough cookbook). Feedforward and feedback control are underemphasised in the discussed strategies.

Discussion

I characterise the comparison in the preceding section by highlighting the weak and strong points of each strategy.

The Shainin System provides powerful tools and a systematic strategy for the discovery of potential influence factors (the exploration phase). This strategy is limited to inductive reasoning from patterns in observational data. Discovery of potential influence factors from opinions and convictions is referred to as "subjective methods" (Shainin, P. 1993), suggesting that objectivity is compromised. This claim cannot be maintained, however, since objectivity is ensured by the experimental verification in the confirmation phase, not by the way potential influence factors are discovered in the exploration phase. In the same paper P. Shainin (1993) claims that using inductive reasoning from observational data is more effective for discovery than using opinions and convictions. But this seems highly situation dependent. In many processes the engineers have knowledge of many influence factors and I see no point in refusing to take this knowledge along as hypotheses (as long as they are experimentally verified in the confirmation phase). Moreover, reasoning from observations will help identify only influence factors that actually vary during usual manufacturing. However, many factors in the process that affect quality and could be used to arrive at improvements are kept constant during normal production, and these will not show up as patterns in observational data. This holds especially for control variables which are not varied during regular production. Shainin deserves credits for emphasising the importance of effective quantitative procedures for the exploration phase, but takes a position which is too rigid to hold in general.

The emphasis in the Shainin system is on the discovery of nuisance variables and disturbances and less on modelling the precise relationships between influence factors and CTQs. Especially, the strategy does not exploit control variables: the observational techniques offered are probably inefficient in discovering them, and the modelling tools required to explore their effects are missing. The improvement patterns in which control variables play a role are not exploited. It seems that when the objective of a project is to identify the unknown root cause of a problem, the method proposed by Shainin is effective. However, in projects in which most influence factors are known or easily identified and in which the emphasis is on modelling their precise effects, the opposite could prove true.

Taguchi exploits the advantages and power of experimental investigation. The methodology falls short in the exploration phase, giving only limited guidance in the discovery of influence factors. Furthermore, the focus is on finding optimal process settings, rather than on gaining understanding of the system, which is reflected in the fact that a loss function is studied instead of a CTQ. In Nair (1992) Shin Taguchi proclaims:

> Notice that the objective of parameter design is very different from a pure scientific study. {. . .} Pure science strives to discover the causal relationships and to understand the mechanics of how things happen. Engineering, however, strives to achieve the result needed to satisfy the customer.

In the same paper, Box, among others, declares his profound disagreement with this claim. An intelligent consideration of various alternative improvement options requires understanding of the system under study in the form of a model.

Both Shainin's and Taguchi's strategies pay only limited attention to the operational definition of the CTQs and the problem and limit this issue to measurement reliability. Especially the empirical verification of the problem definition – as is done in step 4. of the Six Sigma cookbook (establish product capability) – is an important lack.

The breakthrough cookbook of Six Sigma seems the most complete strategy. The division of the 12 steps over the four phases measure, analyze, improve and control seems rather arbitrary from a methodological viewpoint. The guidance and tools that are given for the exploration phase lack a clear structure and coherence.

An aspect that is underexposed in all three strategies is the iterative learning nature of improvement projects. The strategies are presented as "recipes" that guide the experimenter in a straight line to a solution (the designation breakthrough cookbook is pregnant in this context). It is not pointed out to the experimenter that many of his decisions (concerning, for example, the problem definition, specification limits, objectives, potential influence factors) are intelligent guesses at best. The suggestion is aroused that the experimenter's decisions should be perfect at once, whereas experimenters should be taught a fallible and adventurous attitude that is open for new insights. This experimental attitude is promoted eloquently by Box (1999, 2000), and is formulated powerfully in Popper's quote cited below:

> I can therefore gladly admit that falsificationists like myself much prefer an attempt to solve an interesting problem by a bold conjecture, *even (and especially) if it soon turns out to be false*, to any recital of a sequence of irrelevant truisms. We prefer this because we believe that this is the way in which we can learn from our mistakes; and that in finding that our conjecture was false we shall have learnt much about the truth, and shall have got nearer to the truth (Popper, 1963, p. 231).

Conclusions

Following the elements of a methodological framework for quality improvement projects Taguchi's methods, the Shainin System and Six Sigma's breakthrough cookbook were compared. This results in the following characterisations.

The Shainin System is mainly a problem solving methodology. Its applicability is limited to projects that seek to identify the (one or very few) root causes of a problem. It is not suitable for studying a more complex system of influence factors and modelling their effects onto the CTQ. The improvements have the form of corrective action against disturbances or adjustment of tolerances, whereas improvement patterns as robust design and adjustment of the mean are underemphasised.

Taguchi's methods exploit powerful improvement patterns. The methodology falls short in the exploration phase – for which it provides only limited guidance – and the focus on picking optimal settings (as opposed to gaining insight in the system) is debatable.

Six Sigma's breakthrough cookbook is the most complete statistical improvement strategy. It could be improved by systematising the guidance that it provides for the exploration phase. Moreover, it should incorporate more adventurous and fallibilistic attitude that fits experimenters.

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