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Differences and Similarities between Quality Improvement Methods Originating from the USA and Japan

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Abstract
The purpose of this paper is to compare two methodologies for quality improvement, Six Sigma and Science SQC. They are representative examples of their originating countries the United States and Japan. Six Sigma got its shape in the USA during 1980's and Science SQC in Japan in the beginning of 1990's. The latter has been considered as Toyota's scientific quality management methodology. Earlier research in this area has arised the question whether there is interest in Six Sigma in Japan. [3]. This paper is an attempt to contribute to the question whether the Six Sigma methodology is similar to Science SQC?

Keywords: Quality tools, data visualization, multivariate methods, Toyota Production System, Six Sigma

1 Introduction

The practitioners in quality initiatives and process developers have often asked whether and how the Japanese industry is involved in using the Six Sigma methodology. This mainly US driven approach is widely believed as being able to achieve quality levels beyond other methodologies. The common opinion has varied between no identified similarity and sometimes a heated discussion whether there exists a similar approach with a different name. [6]

The authors of this paper have found and studied a source of information that seems to approach the above question with a rich set of detailed examples. Kakuro Amasaka's Science SQC, New Quality Control Principle - The Quality Strategy of Toyota [1] illustrates the quality practices by Toyota corporation approximately during the decade 1990-2000. The price for this information is a relatively high barrier to be climbed over in order to understand the content of the book which appears to be rather an uneven compilation of research papers of Amasaka. Same topics repeat several times in slightly varying viewpoints - making the text difficult to access. Some details appear to be also contradictory to each other in many places.

The same topic has been covered a decade later with another study - again with a change of viewpoint - from SQC to TQM. The title of this new publication is Science TQM, New Quality Management Principle: The Quality Management Strategy of Toyota. The structure of the later book is even more clearly a collection of research papers. The scope of this study is on the findings within the first book.

This paper is a modest effort in reaching to see a phenomenon that seems to have eluded wider recognition during the past 15 years, regardless of many published texts and continuous research.

2 Methods

The research method is based on a combination of literature review and assessment based on authors' experience. Two of the authors have acquired Six Sigma Black Belt certifications. The literature review has been carried out by studying widely Six Sigma articles and Kakuro Amasaka's Science SQC, New Quality Control Principle [1].

3 Six Sigma

Six Sigma is "primarily a methodology for improving the capability of business processes by using statistical method to identify and reduce or eliminate process variation" [7]. It is a quality concept where the immediate goal is the improvement of yield by defect reduction. Higher yield and better quality reduce cost and improve customer satisfaction. Defect reduction is also intended to result in immediate cost reduction. [14] "Six Sigma is uniquely driven by close understanding of customer needs, disciplined use of facts, data, and statistical analysis, and diligent attention to managing, improving, and reinventing business processes" [11].

The statistical representation of Six Sigma describes quantitatively how the process is performing. The goal of Six Sigma is to design processes that do what they should do with very high reliability, ultimately producing very consistent products and services [8]. The numerical goal of Six Sigma is to reduce defects in the process to the level 3.4 parts per million also known as Defects Per Million Opportunities (DPMO).

Six Sigma methodology uses two different methods to reach two main goals, customer satisfaction and cost reduction, through the reduction of process variation. Two approaches for Six Sigma projects can be identified: DMAIC (Define-Measure-Analyse-Improve-Control) and DFSS (Design For Six Sigma). The DMAIC approach is applied in the context of the realisation of products and services (core and support processes). [12] The DFSS approach is applied in designing new products and processes. This article concentrates in DMAIC.

3.1 DMAIC method

A Six Sigma project requires a structured approach, providing an effective execution for its success [7]. Six Sigma improvement process usually follows the DMAIC process. In the **D**efine phase the process or product that needs improvement is identified thoroughly. Developing appropriate metrics is a major activity of Six Sigma deployment because Six Sigma emphasizes decision making based on fact and data [2]. In following the **M**easure phase those characteristics of the product or process that are critical to the customer's requirements for quality performance and which contribute to customer satisfaction are identified and measured. Evaluation of the current operation of the process is made during the **A**nalyse phase to determine the potential sources of variation for critical performance

parameters. In the **I**mprove phase those product or process characteristics which must be improved to achieve the goal are selected and the chosen improvements are implemented. After implementation the new process conditions are verified, documented and monitored i.e. via Statistical Process Control methods (SPC) in the **C**ontrol phase. Depending on the outcome it may become necessary to revisit one or more of the preceding phases [4].
One goal of using DMAIC methodology is to identify the root cause of the problem and to select the optimal level of the CTQs (Critical to Quality) to obtain the desired output [5]. CTQs are used to decompose broad customer requirements into more easily determined and measured elements.

Six Sigma provides different methods and tools from two fields, **statistics** (such as methods of statistical analysis, Gage R&R or the tools of Design of Experiments) and **quality management** to ensure customer orientation in the product development and failure prevention). [12]

Although Six Sigma is primarily based on statistical methodologies, it has integrated other quality management tools e.g. a cause and effect diagram, poka-yoke, kaizen, kanban, lean manufacturing and QFD [7]. The survey made by Miguel et al [10] revealed that the ten tools which are used most by the companies which applied the DMAIC method in the Six Sigma projects were data collection, histograms, Pareto diagrams, brainstorming, control charts, capability indices, flow charts, process maps, assessment of the measurement system and statistical process control.[10] Tools which were mentioned to be most used are basic and relatively simple quality tools.

4 Science SQC

According to Amasaka, Science SQC (abbreviated as SSQC in this paper) is in principle a methodology to help identify cause and effect correlations of apparently disorganized facts [1]. A deeper goal for the utilization of the methodology is to create universally applicable technical solution patterns in technology development.

The concept includes four main items, called cores:
1. The SSQC methodology itself - a systematic use of statistical methods for problem solving through the whole process from requirement definition to the finished product.
2. SQC technical methods - a pattern for using the tools. The workflow is called Mountain climbing for problem solving.
3. Total Technical Intelligence System (TTIS) is a collection of support tools that are used for creating and dissemination of insights learned while applying the process.
4. Management SQC means the handling of organizational issues. The goal is to transform the technical problems into the problems of organization.

The Science SQC concept is defined in the context of Toyota's TQM process and in the three key processes Toyota Marketing System (TMS), Toyota Development System (TDS) and Toyota Production System (TPS). These key processes are presented as a circular flow of information where Amasaka's SQC methodology is in the center and is intended to provide an improved visibility and understanding across the whole system.

The SSQC methodology itself is not as distinctively identifiable as the DMAIC of Six Sigma. Therefore it is explained here by describing the other three core items. The primary objective is to enable excellence in the quality, cost and delivery (QCD) paradigm through the insight gained by the use of the methodology.

4.1 Mountain climbing for problem solving

The toolset of SSQC is arranged along a three phase problem solving process. The closer details are discussed later in the comparison chapter.

The purpose of the first phase - New seven tools for TQC - is structuring the problem and topic selection. This combination of tools was created and promoted in 1979 by the Union of Japanese Scientists and Engineers (JUSE) - known also as seven management and planning tools.

The second phase is perhaps the most interesting part of the SSQC. This is the first time when the authors of this paper see statistical multivariate data visualization used in general industrial quality practice. Multivariate analysis (MA) is labelled as problem solving, level 1. According to Amasaka [1] having this phase completed typically yields up to 70…80% of efforts towards the goal in solving a problem. A typical method is Principal Components Analysis (PCA). Some examples are provided where this method has been used for visualizing of correlation patterns.

The third phase is named Design of Experiment (DE) - more commonly abbreviated elsewhere as DoE - labelled here as problem solving, level 2. Performing statistically designed experiments helps to confirm and optimize the solution.

4.2 Total Technical Intelligence System (TTIS)

TTIS is a complex support system for storage and retrieval of engineering information within the context of SSQC. It consists of four subsystems, TSIS, TPOS, TIRS and TSML.

The Total SQC Intelligence System (TSIS) is a library of SQC application examples. It can be divided into further four interlinked subsystems: quick registration and retrieval library - one page flowchart references (TSIS-QR), reference book - more detailed information (TSIS-RB), practice manual (TSIS-PM) and mapping library (TSIS-ML).

The Total SQC promotional original software (TPOS) is a software package for process practitioners running in personal computers. The software consists of several packages, multivariate analysis (TPOS-PM), basic SQC (TPOS-PS), design of experiments (TPOS-PD), sensory evaluation (TPOS-PK) and reliability analysis (TPOS-PR).

The Total Information Retrieval Systems (TIRS) was defined as a separate system for technical reports and engineering books.

The Total SQC Manual Library (TSML) is a collection of classified instructions for performing the SQC process itself.

The above components of information system were presented as part of the process core. Amasaka [1] continues the list with one major information system - Availability and Reliability Information Administration System (ARIM-BL). It integrates offline, inline and online measurement information from the car body assembly line. This system controls the process in real-time. The integrated information enables real time visibility to both products and the condition of the assembly line.

4.3 Management SQC

The higher goal of this fourth core item is to strive towards universally applicable solutions instead of individual solutions with a narrow scope.

The method recognizes six communication gaps between planning, designing, manufacturing and marketing departments that are to be improved. Managers responsible for resources are required to clarify business processes by practicing task management team activities within and among departments. [1]

Previously explained problem solving process is presented in an extended form in the context of Management SQC. The first part - the seven new methods is called market survey. The second step consists of MA and DE phases. The extended part is called optimization and includes procedures like Monte Carlo simulation and market surveys.

5 Comparison

5.1 Goals

Both methodologies value broadly similar goals. Figure 1 illustrates this and also a difference in the short term / long term expectations.

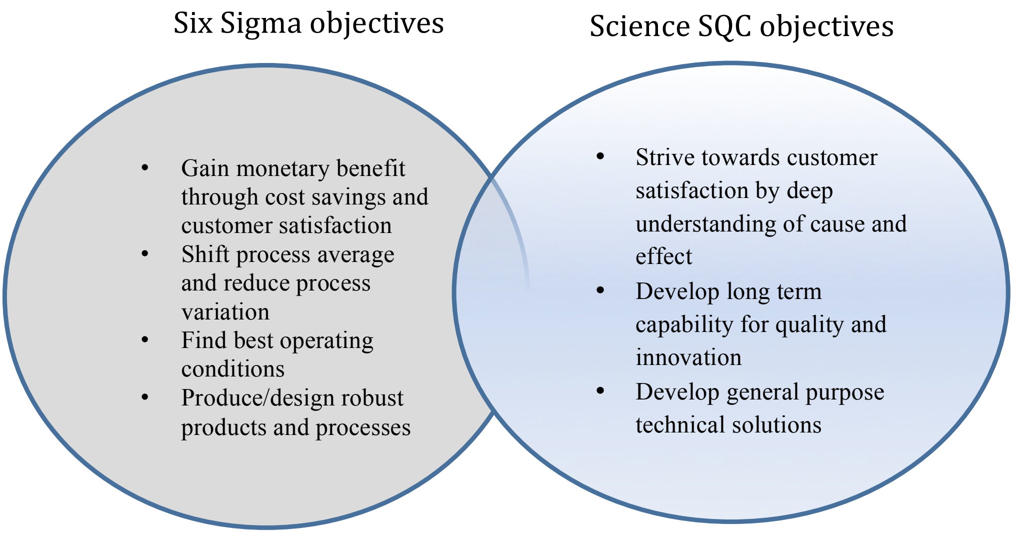

Figure 1. Comparison of goals in Six Sigma and Science SQC

5.2 The scope of application

In the light of the above descriptions, these methodologies differ significantly in their scope of application. Six Sigma can be applied to a wide range of processes where variation is regarded as undesirable. Within the DMAIC thinking it is enough to standardize the impact of improvement into the process. Many companies using Six Sigma have gone further and adopted project library practices in order to enable access to lessons learned in the past improvement projects.

Six Sigma and the Science SQC approach have both been created within the process framework and organizational culture of one large corporation - Motorola and Toyota. Unlike Six Sigma, the latter approach seems to have stayed only within the originating environment. SSQC is integrated very deeply into all activities of corporate's processes. The complex linkages to the host processes and supporting structures indicate that continuous organizational learning and development have higher priority than the immediate solution to an engineering problem.

5.3 Tools

Amasaka's study [1] illustrates the details of problem solving process in several slightly different forms. The authors of this paper have used experience based assessment in setting up a matrix diagram for identifying similarities in the toolsets of Six Sigma and Science SQC.
The chosen lists of tools should be considered as typical and not specific to any particular implementation.

Table 1. The similarities between the toolsets of Six Sigma and Science SQC

Six Sigma phases and tools / Science SQC tools and phases for problem solving	**New 7 tools for TQC (N7)**	Affinity diagram	Interrelationship diagram	Tree diagram	Matrix diagram - e.g. this diagram	Matrix data analysis diagram	Process decision program chart	Activity diagram	**Multivariate analysis (MA)**	Cluster analysis	Analyzing source of variation factor	Principal component analysis	Multivariate analysis	Creation of model	plan-do for improvement (1)	**Design of experiment (DE)**	Design of experiment	Plan-do for improvement (2)	Verifying of mechanism	**Optimization**	Simulation	Market surveys	
DEFINE																							
Business case																							
Project charter																							
SIPOC map																							
Process yield								x															
Critical to quality (CTQ) tree		x	x	x																			
Voice of customer (VOC)																						x	
MEASURE																							
Process mapping							x	x															
Priorization matrix, FMEA					x	x																	
Measurement system analysis (MSA, Gage R&R)																							
Data visualization										x													
Control chart																							
Process capability (Cpk)																							
Process sigma level																							
ANALYSIS																							
Process door - a detailed process analysis								x						x									
Data door - visualization with data										x													
Hypothesis testing											x												
Correlation and regression analysis												x	x	x									
IMPROVE															x			x					
Design of experiments (DoE)													x				x				x		
Simulation														x							x		
FMEA update																							
CONTROL																							
Control chart																							
Process change management																							
FMEA updated																							
Mistake proofing (Poka-yoke)							x																
Financial validation																							
Report																							

Yellow cell = no match found

The table 1 itself is an example of using matrix diagram for identifying relations between two sets of concepts. The symbol "x" indicates a similarity in purpose between tools in each set. The tool groups (but not the individual tools) in both sets are ordered chronologically in the table according to their intended application. The identified similarities are aligned approximately along the diagonal of the matrix - a support for the assumption that the problem solving practices are similar. There appears to be no matches for the Control phase of

Six Sigma. One explanation can be found by the location of the reference to the control chart tool. The tool is mentioned in the context of the TPS process.

Both methodologies include a large set of tools. Some closely matching tools can be found, especially in the initial problem identification. Statistical methods are similar in a broad sense. SSQC applies some statistical modelling methods not included in the Six Sigma toolbox, e.g. factor analysis and multivariate analysis. The use of principal component analysis (PCA) was explained by some illustrated case examples that reveal a visual interpretation approach that appears rarely in published material.

5.4 Training patterns

5.4.1 Training in Six Sigma

A well matured business ecosystem exists for Six Sigma training. There are even several sources which provide services as accreditation bodies for Six Sigma training providers.
The successful Six Sigma implementation in an organisation depends on three broad and overlapping key elements; committed leadership, right project and right people. [15] . Training the employees involved in the Six Sigma programme is one of the infrastructure requirements needed to sustain Six Sigma in the companies. Six Sigma prioritises careful selection of the personnel as well as choosing and training the teams for the selection, implementation, execution and evaluation of the results obtained with the projects executed, which are the bases that sustain the program. [10]

The project team consists of the Champion, Master Black Belt, Black Belt, Green Belts and Yellow Belts. The choice of candidates for six sigma expert (Master Black, Black or Green belt) should be carefully made taking notice of the risks that an unsuccessful choice could generate and it should be based on indication or recommendation inside the organisation itself, always supported by the professional's history and performance. This is due to the fact that significant resources are invested in training these professionals and significant responsibility maybe attributed to their job positions in order to make the project fully successful. [10]

5.4.2 Training structure and practices for Science SQC

Amasaka refers to a Toyota-wide SQC seminar in 1967 as a starting point for the development of SQC as engineering problem solving paradigm. This initial activity produced SQC manuals and other useful material.
The SSQC organization and training had evolved to a hierarchical structure consisting of many layers. Table 2 illustrates this hierarchy with intended training distribution.

Table 2 Training levels and target attendant ratios in Science SQC nad Six Sigma

Training level	Target attendant ratio (%)
SQC Special Advisor	2
Upper Advanced	5
Lower Advanced	15
Intermediate SQC	60
Business SQC	100
Beginner SQC	100

Training level	Target attendant ratio (%)
Champion/Sponsor	0.3-0.5 (author's estimate)
Master Black Belt	0,1
Black Belt	1-2
Green Belt	30

The beginner level training consisted of four days introductory course, practical work, bringing the theme for improvement project from the attendee's own work environment and completion of the theme within one year. One fourth of the curriculum was dedicated for guidance meetings and case seminars. Lecturers were mainly in-house.

The intermediate training level included options for special focus areas, reliability or multivariate analysis. The training staff was supplemented by university professors and attendees of previous classes.

The training staff for the two advanced level trainings included several top level university researchers and inhouse engineers at manager level or higher positions. The curriculum took the attendees through the application of SSQC in the major process areas of TMS, TDS and TPS. The trainees at this level spent one year in research of their own registered theme after completion of the course and they presented the results at the next seminar. The goal was to boost the performance of workplace supervisors and the ability to guide others.

At the top of the training hierarchy the Toyota-wide SQC seminar was revised and positioned to provide competences needed in the future. It consisted of three workgroups, design evaluation, process design for production engineering and process control for manufacturing divisions. Their objectives included research on high quality practical themes, continuous revision of SQC manuals mentioned as visible footprints of each course and becoming as SQC "spark plugs" in workplace with the ability to guide.

As a conclusion to the training pattern comparison it is easy to see many similarities like the level structure with similar purposes, the emphasis on trainee interaction and interaction with the work environment, the intent to use real problems from attendees' responsibility area. It has also been important to ensure continuity by using attendees as lecturers.

5.4.3 Training volumes

Verifying the commitment by studying the training statistics would be a good topic for further study. Some Six Sigma training volume figures have appeared occasionally in various contexts during the years. Amasaka's study [1] provides only a scarce insight to the actual situation. It describes a training plan 1996-2001 for a total of 3000 engineering managers, of whom 2200 had a position director down to department managers. The total training target was 17000 persons. 800 SQC Special Advisors and 1100 Upper Advanced level practitioners were trained at the highest training levels.

6 Later research in the context

The research within the SSQC methodology has continued since the publication of original ideas about 15 years ago. A recent very interesting paper brings the terminology studied above into the context of data intensive methods in product design with the goals set to prescriptive analytics capability [16]. Prescriptive analytics goes beyond traditional prediction - suggesting decision options in the domain of the question - instead of only extrapolating and visualising the values of variables. The SSQC system technical elements are also illustrated in the updated information technology setup.

7 Conclusions

This study has compared the Six Sigma and Science SQC quality methodologies in three viewpoints - the scope of application, toolsets and training patterns. Some properties support the assumption of similarity. The idea of Deming PDCA cycle can be identified in both. Their problem solving logic apply their toolsets in a similar pattern. Training procedures contain corresponding elements. Practitioners learn, reflect their new skills in work by solving practical problems and report their experiences back to the learning community. In both cases the learners consolidate their skills by teaching at lower competence level sessions.

The focus towards gaining short term financially verifiable savings is characteristic for Six Sigma and takes it apart from Science SQC although both are customer satisfaction oriented. The strength of Six Sigma lies in the organisational framework for deployment accompanied by structured and analytical tools for problems resolution [13] .

Understanding the complex process integration and the involvement of management - beyond just applying the problem solving process and tools - supports the conclusion that Science SQC values the continuous development of organization's capability more than getting the immediate solution to a problem. The identification of six gaps is an example of an effort to remove organizational silos from obstructing the deployment of a technical solution. The plan for training significant amount of upper level managers to upper SSQC competence levels is a major difference to Six Sigma where managers may have only a brief awareness update.

The use of multivariate modeling methods - PCA and factor analysis illustrated in many examples - is a further significant difference between the two methodologies. The Science SQC approach in visually rich modeling resembles other experiments with the same tools [9]. A multivariate projection is not an easy-to-share representation for practical product development work but it has been demonstrated to have a great power to reveal patterns of cause and effect correlations in apparently disorganized facts quickly.

As the final conclusion authors would like to encourage further research in the integration of advanced quality methods with organization's processes and in understanding the role of this kind of an approach in the development of quality and innovation capability.

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