SIX SIGMA: A LITERATURE REVIEW

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ABSTRACT

Despite stiff international competition in the global market, world-class manufacturers are increasing their market share and profits through low-cost production, waste reduction in manufacturing, production of high quality products, and exceptional customer service. Six Sigma has been successfully implemented in this regard. In this paper, a selected survey of Six Sigma literature is presented to illustrate the wide scope of the application of the concept. This could be of immense benefit to organizations' top management who need to understand the critical variables and factors for the successful implementation of Six Sigma programmes, leading to substantial, sustainable long-term improvement in performance results, value for money, and effort. The paper presents motivated pointers – substantiated as far as possible by data and evidence – to key success factors, variables, and their interrelationships.

OPSOMMING

Sterk internasionale mededinging ten spyt verhoog wêreldklasvervaardigers hul markaandeel en winste via laekosteproduksie, skrootvermindering, die produksie van gehalteprodukte en die lewering van primadiens aan klante. Ses Sigma is in hierdie verband as gereedskap suksesvol geïmplimenteer. Die artikel behandel 'n gekeurde oorsig van Ses Sigmaliteratuur om sodoende die toepassingsveldwyde van die konsep te illustreer. Die artikel is nuttig vir organisasiebestuurders uit die oogpunt van veranderlikes en suksesfaktore wat deur die Ses Sigmametode tot substansiële en volhoubare langtermyn verbeterings van 'n onderneming kan lei.

1. INTRODUCTION

In the current decade, organizations face increasing complexity and uncertainty arising from competition, globalisation of industrial activities, diversification of culture, individualisation of lifestyle, and the growing consideration for the natural environment. The increasing complexity and uncertainty cause practical and theoretical difficulties in all domains of organizational management. Thus, as competition becomes intense, more pressure is exerted on organizations to improve product/service quality and customer satisfaction. In this regard, Six Sigma has emerged as a useful tool for solving organizational problems, particularly those relating to improving customer service quality, which in turn improves profitability.

'Sigma' is a Greek letter denoting the standard deviation of a random variable (i.e. variability), and is applied as a statistical process technology measure in organizations [21, 45]. Top management in organizations should understand that the Six Sigma method is a quality improvement programme that allows organizations drastically to improve their bottom line (through organizations' products, services, and processes) by designing and monitoring everyday business activities in ways that minimise waste and resources, while enhancing customer satisfaction [4, 18]. Six Sigma can reduce defects to as low as 3.4 parts per million in an organization [37, 58]. It is widely advocated by giants in the aerospace and electronics industries and in healthcare, in view of its potential to reduce cost and shorten cycle times [18]. McClusky [46] shows why a 99% quality level is not acceptable – a gap that Six Sigma can bridge: (i) at major airports, 99% quality means two unsafe plane landings per day; (ii) in mail processing, 99% quality means 16,000 pieces of lost mail every hour; (iii) in power generation, 99% quality will result in 7 hours without electricity each month; (iv) in medical surgery, 99% quality means 500 incorrect surgical operations per week; (v) in water processing, 99% quality means one hour of unsafe drinking water per month; (vi) in credit cards, 99% quality will result in 80 million incorrect transactions in the UK each year.

The introduction of Six Sigma in manufacturing systems was a springboard to revolutionising the scope and use of quality systems in business today [21, 45, 61]. The benefits of Six Sigma are only gained by organizations that apply it wisely. Top management should be able to assess their organization's readiness for a Six Sigma programme, and also to estimate the time and effort required for its successful implementation. Two variables that would help in this regard are (i) understanding the current use of quality programmes in the organization, and (ii) the organizational understanding of the measurement of its processes [28]. The major challenge to top management is the highly competitive global market, which requires the production of high quality products with less energy; and resource consumption is one of the incentives responsible for the current level of development of Six Sigma [42]. Floot [18] notes that the Six Sigma phenomenon appeals to many, especially the top hierarchy in an organization, because some major corporations report exceptional returns on their Six Sigma investments. However, understanding the key features, obstacles and shortcomings of Six Sigma methods allows top management better to support their strategic directions and increasing needs for coaching, mentoring, and training [37].

Historically, the roots of Sigma as a measurement standard go back to Carl Fredrick Gauss (1777-1855), who introduced the concept of the normal curve. Walter Shewart introduced 'three sigma' as a measurement of output variation in 1922, and stated that process intervention was needed when the output went beyond this limit. The 'three sigma' concept is related to a process yield of 99.973%, and represents a defect rate of 2,600 per million, which was adequate for most manufacturing organizations until the early 1980s [51]. Six Sigma methodology was strengthened from statistical process control (SPC) concepts from the 1960s to the 1980s, and produced tremendous successes in a variety of industries. General Electric (GE) and Motorola are two of the best known success stories of Six Sigma activity [24]. Other organizations that have recorded successful implementation of Six Sigma in the US, Europe, and Asia include IBM, Raytheon, Sony, Lockheed Martin, Nokia, Bank of America, Honeywell, Mount Carmel Health System, and DuPont. An additional list includes Samsung, Starwood Hotels, Boeing, Toshiba, Seagate, Kodak, Texas Instruments, Borg-Warner Automotive, GenCorp, and Navistar International [6, 24, 27, 38, 51].

Typical responsibilities of a Six Sigma top management team may include the following [56]:

- developing job descriptions and compensation programmes for Six Sigma facilitators (called black belts);
- preparing the strategy for training black belts;
- ensuring the availability of information technology resources necessary to track Six Sigma projects;
- developing the tools and metrics for measuring and validating the financial returns of Six Sigma projects; and
- preparing a strategy for communicating Six Sigma to the organization's internal stakeholders: managers, employees, and others.

In the 1980s, application of the Six Sigma methods allowed top management to sustain their competitive advantage by integrating their knowledge of the process with statistics, engineering, and project management [2]. Harry [26] studied the basic concept of Six Sigma at Motorola Inc. in the USA in 1987 [24]. Motorola faced the threat of Japanese competition in the electronics industry at this time. They found that they were losing a large portion of their business and productivity through the cost of non-quality levels, in order to maintain their customers and attract new ones [26]. Motorola effectively utilised Six Sigma to express its quality goal of 3.4 Defects Per Million Opportunities (DPMO), where a defect opportunity is a process failure that is critical to the customer [40].

Motorola set this goal so that process variability is ±6 Standard Deviation (SD) from the mean [11]. The company further assumed that the process was subject to disturbances that could cause the process mean to shift by as much as 1.5 SD off the target [16]. It was believed that factoring a shift of 1.5 SD in the process mean resulted in a 3.4 DPMO [11, 40]. This goal was far beyond normal quality levels, and required very aggressive improvement efforts. For example, Three Sigma results in a 66,810 DPMO or 93.3% process yield, while Six Sigma gives only 3.4 DPMO and

99.99966% process yield (these computations assume a 1.5 SD shift in the process mean). Figure 1 shows the relationship between DPMO and process sigma, assuming the normal distribution [40].

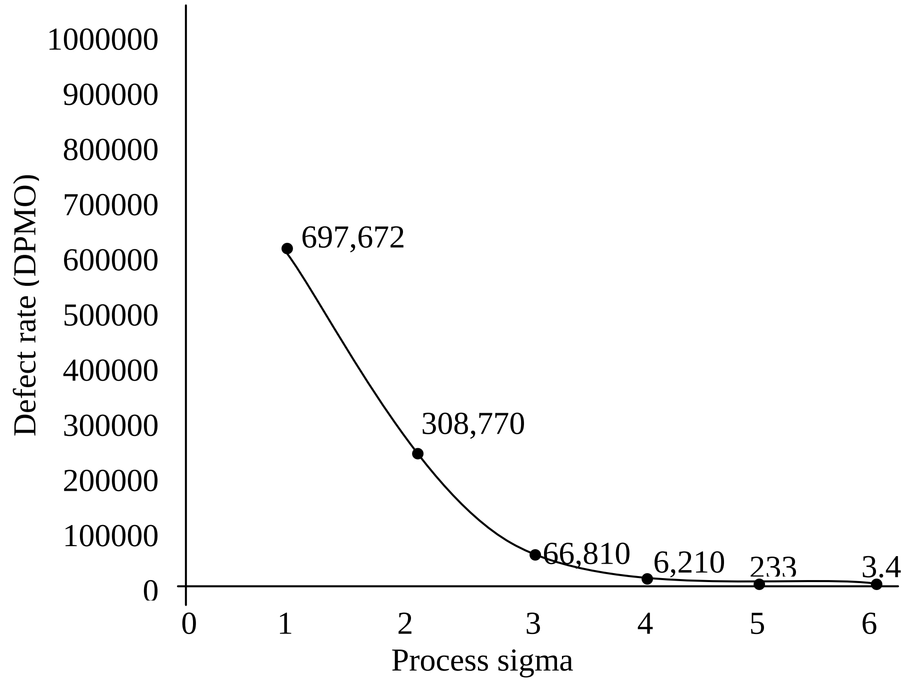

Figure 1: Defect rate (DPMO) versus process sigma level (Source: [40])

One of the first steps that top management must consider in the improvement process is to measure the current process sigma by defining current process defects in customer terms (critical-to-quality metrics). These measures are converted to DPMO and then to the current process sigma. As a rough guideline, the improvement rule, using the performance gap, is often used to establish the goal for defect reduction. For example, if the baseline data from the process has a DPMO of 66,000, then the rule sets the improvement goal at 66,000 DPMO. Figure 2 illustrates the relationship between specific challenging goals employed in Six Sigma and performance.

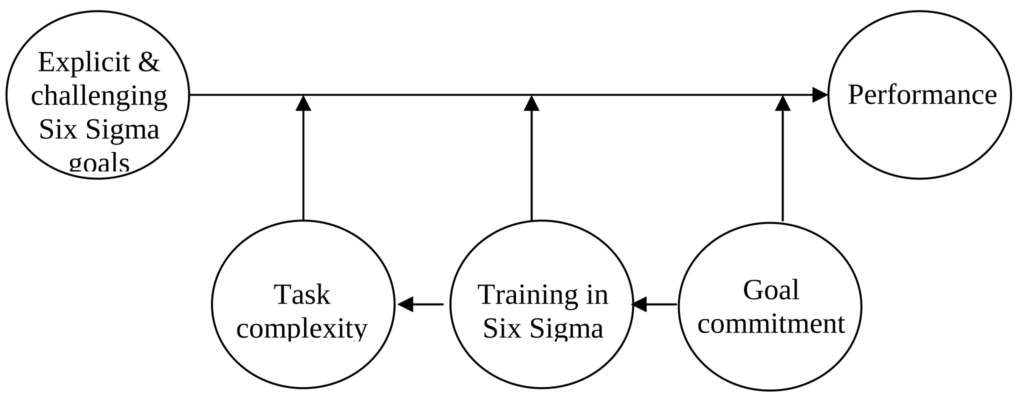

Figure 2: Explicit Six Sigma goals and performance (Source: [40])

When Six Sigma improvement projects use specific quantitative improvement goals like a challenging DPMO reduction more effort is expended (see Figure 3) [40].

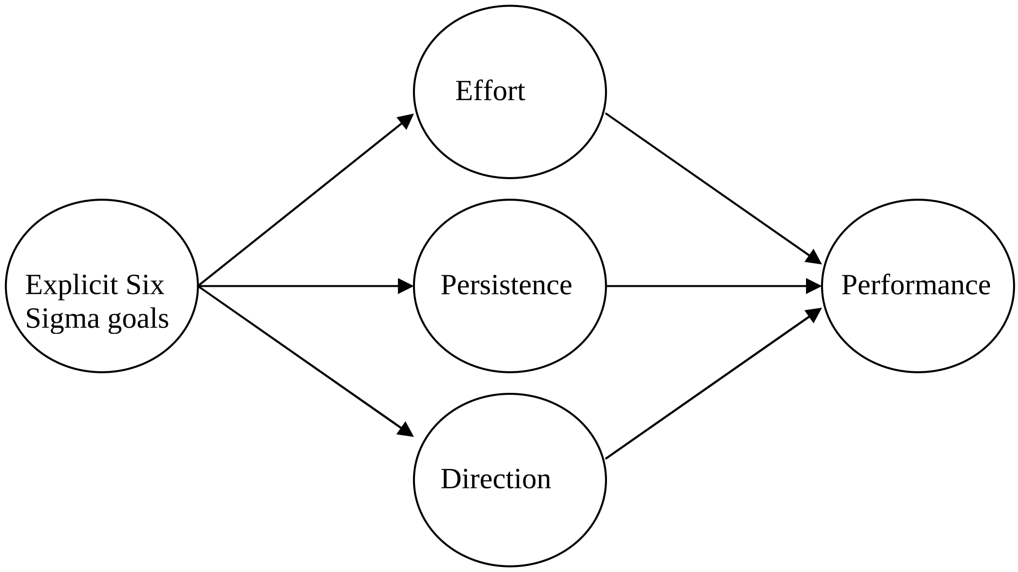

Figure 3: Mediating variables between Six Sigma goals and performance (Source: [40])

In addition, Six Sigma is a well-structured problem solving and continuous improvement methodology applied in a variety of world-class companies such as General Electric (GE) and Motorola. Problem-solving and improving existing systems with Sigma are achieved through the DMAIC process (Define, Measure, Analyse, Improve, and Control), while incorporating Six Sigma in the design of new systems is achieved through the Design for Six Sigma (DSS) process (Define, Characterise, Optimise, and Verify) [56].

Sigma Rating (SR) provides a statistical quantitative metric that can help top management to determine a process's performance. A process is considered Six Sigma and capable when its performance achieves less than 3.4 DPMO. A normal probability table is utilised to determine the Sigma rating of the process, given the process DPMO. A defect here is a performance level that is not meeting the designer's specification rather than customers' expectations. Examples of such measures in the context of simulation modelling include system throughput (yield), manufacturing lead time, operations efficiency, scrap and rework rates, service times, delivery time, and so on. Different system variables often contribute to variation in such performance measures. Examples include factors of inter-arrival times, buffer capacities, line speeds, machining parameters, processing times, equipment failure rates, and so on.

Based on the foregoing discussions, an important question may be: Has worldwide experience shown that implementation of Six Sigma is worth the effort and cost? In recent times, when the economic recession of companies is characterised by a slowdown in demand, top management look for opportunities to cut costs and to deploy scarce funds wisely [57]. It is obviously worthwhile for management to deliberate on whether or not to introduce Six Sigma [57].

For several years, Six Sigma has been studied from a variety of different academic perspectives, based on economics (such as cost economic transactions and resource-based issues) and mathematics (application of decision science, simulation, and mathematical models) (for example, [1, 5, 7-10, 14]). A number of attempts have been made to integrate Six Sigma and other techniques. Representative studies include the integration of Six Sigma and the customer quality improvement technique [49], and customer-centric Six Sigma quality and reliability management [36]. Another study has integrated the analytical hierarchy process with the Six Sigma framework [5].

The motivation for Six Sigma is that every improvement activity should be based on data, rather than on emotional, abstract, or subjective discussion [24]. Six Sigma has been viewed from physiological, psychological, and sociological perspectives on human behaviour in its application to industry. Another perspective relates to skills and competencies in its uses. Therefore, the breadth and depth of study and perspectives in Six Sigma research provides a wide range of opinions and views on the subject. In future, it may be that Six Sigma will continue to develop from a disparate collection of studies into an academic discipline in its own right.

The present state of the literature is such that little emphasis is placed on providing a unified theory of Six Sigma [15-17, 21-23]. Many scholars appear to find it difficult to agree on the concept. Often, similar established terms – such as total quality management and quality assurance – are used interchangeably for this important concept [41, 44, 55, 56, 59, 60]. Some scholars and professionals, in academic and industrial communities, seem not to appreciate that Six Sigma is more often used by organizations that are on a journey of achieving and sustaining significant financial savings to the bottom line. It is also equally applicable to those organizations that would like to embark on a journey towards improved capability or 'best-in-class' management practice. This work is therefore an effort to review past studies, and to highlight the questions that future investigators should attempt to answer. Hopefully, this work stimulates research in this highly valued research area.

This paper consists of four main parts. The introduction provides the motivation for the study, the research objective, and the expected contributions. The next section is a review of related past work on Six Sigma. The literature is classified into methodologies and tools, and application/implementation. Section three considers the critical variables and factors for successful implementations of Six Sigma. The final section of the paper is based on some insights gained into the literature on Six Sigma, and suggests possible areas future researchers could investigate in order to increase our understanding and to extend the frontier of knowledge on Six Sigma implementation practices.

2. LITERATURE REVIEW

2.1 Six Sigma as a methodology for quality management

Six Sigma methodologies and tools are wide ranging. Six Sigma is seen as a methodology to total quality management [38]. The authors argue for Six Sigma as a methodology within the larger framework of total quality management. However, although the Six Sigma methodology can be readily applied to many different improvement opportunities, the author notes that real-world systems are often complex, dynamic, and stochastic in nature. This results in difficulties in representing their actual behaviour as well as in attempting to optimise and plan their performance. Thus, various elements of randomness and uncertainty in system operating conditions, along with the dynamic interactions among system elements, often lead to inconsistent performance (response signal) over time. This complicates and increases the cost of system control and planning, and impacts on the delivery of products and services. Such difficulties exist in a great number of applications in areas of product development, manufacturing, and enterprise resource planning. A classic investigation on how to achieve Six Sigma rating – using a system simulation modelling approach that combines robust performance, minimal non-conformities, and the flexibility of simulation modelling to improve the performance of production and business systems – was presented by Al-Aomar [1].

Using Six Sigma as a quality management tool is also supported by research in the classification of general aspects of Six Sigma by Odeandaal and Claasen [48]. The paper focuses on the use of Six Sigma methodologies as a tool in achieving excellence in total quality management implementation in manufacturing environments. The case examined a manufacturing plant. Specifically, the authors explained the basic concepts of Six Sigma, explored their relevance, and shared some early results. The thesis of the work focuses on measuring, analysing, and the controlling cycle. The experience shared by the authors is that the company's bottom line could be improved by adopting Six Sigma as a total quality management tool.

Six Sigma business strategies and principles	Six Sigma tools and techniques
Project management Data-based decision-making Knowledge discovery Process control planning Data collection tools and techniques Variability reduction Belt system (Mater, Black, Green, Yellow) DMAIC process Change management tools	Statistical process control Process capability analysis Measurement system analysis Design of experiments Robust design Quality function deployment Failure mode and effects analysis Regression analysis Analysis of means and variances Hypothesis testing Root cause analysis Process mapping Signal to noise ratio

Table 1: Six Sigma strategies, principles, tools, and techniques [3, 37]

Statistical process control (SPC) is a function in a production process that finds deviations from the optimum process outputs, and uses proactive means to look for any process shifts before product quality is compromised [51].

2.2 Six Sigma tools

There are several tools available to top managers that can be used by a Six Sigma organization in achieving the desired objective. Table 1 summarises Six Sigma business strategies, tools, and principles [37]. These tools and techniques are well documented and widely available in the body of knowledge contained in Six Sigma literature and/or web sites.

Company/project	Metric/measures	Benefit/savings
Motorola (1992)	In-process defect levels	150 times reduction
Raytheon/aircraft integration systems	Depot maintenance inspection time	Reduced 88% as measured in days
GE/Railcar leasing business	Turnaround time at repair shops	62% reduction
Allied signal (Honeywell) laminates plant in South Carolina	Capacity / cycle time Inventory / on-time delivery	Up 50% / Down 50% Down 50% / Increased to near 100%
Allied signal (Honeywell) bendix IQ brake pads	Concept-to-shipment cycle time	Reduced from 18 months to 8 months
Hughes Aircraft's missiles systems group / wave soldering operations	Quality/productivity	Improved 1,000% / improved 500%
General Electric	Financial	$2 billion in 1999
Motorola (1999)	Financial	$15 billion over 11 years
Dow Chemical / rail delivery project	Financial	Savings of $2.45 million in capital expenditures
DuPont/Yerkes plant in New York (2000)	Financial	Savings of more than $25 million
Telefonica de Espana (2001)	Financial	Savings and increases in revenue 30 million Euro in 10 months
Texas Instruments	Financial	$600 million
Johnson and Johnson	Financial	$500 million
Honeywell	Financial	$1.2 billion

Table 2: Reported benefits and savings from Six Sigma in manufacturing sector (Source: [5,12,16,38,47]

2.3 Six Sigma in the manufacturing sector

Six Sigma has been applied to a number of processes and projects in the manufacturing sector. A number of these projects are reported in Table 2. As shown in Figure 4, the application of Six Sigma in industries is wide and diverse. For example, extensive reports have been documented on Six Sigma application in healthcare (see details in Table 3 and Figure 5). In the manufacturing sector, successful implementation of Six Sigma has been reported (see Table 2). From Figure 4, much research and many applications are needed in banking services, higher educational institutions, and food services. Although studies in the software industry are rated high, extensions of the current studies in this industry are warranted.

The DMAIC process has been one of the primary tools within Six Sigma adopted in manufacturing environments. This section provides a good example of the DMAIC process, but is simplified below for ease of understanding.

- In essence, a problem is defined (mapping the process) and converted into a statistical/mathematical problem: $Y = F(x_1, x_2, x_3, \ldots, x_n)$. That is, the process output is a function of many inputs.
- The various phases of DMAIC then try to reduce the number of inputs (x's) that affect the problem Y (while verifying the integrity of the data).
- Ultimately, only a few x's need to be controlled in order to ensure improvement (the DMAIC process determines this by establishing interactions of inputs and their effect on the output Y).

The above general framework is now illustrated in two cases.

Yusuff and Karim [64] made an interesting application of the DMAIC process in the surface mount technology (SMT) industry, where various factors contribute to waste and machine efficiency [32]. From the study of machine loss time, it was found that model change and the partswear process were the main contributors to machine loss time. Results of tests of population variance and population means showed an improvement in metrics. A 35% increase in SMT machine capacity was achieved, with an average of 4.0 million shots daily, with a TEP (Total Equipment Productivity) of 70%. Although the process had not achieved Six Sigma capability, SMT machines improved tremendously in productivity and annual profit gain.

Rohani and Dimyati [54] investigated the theory and practice of applying Six Sigma in machining and sub-assembly processes. The study reduces the scrap generated during machining, which contributes the highest percentage of scrap value (0.53%) owing to hole offset. Four factors were identified as sources of the problem: jig design, loading method, machine alignment, and cutter design. In the Analyse phase, hypotheses testing showed that only three factors have an impact on mean and variance of the process, namely jig design, machine alignment, and cutter design. The study specifically focused on the improvement phase, which is applying Design of Experiments (DOE) to determine the influence that the three factors (jig design, machine alignment, and cutter design) have on the output response (dimension). DOE results show that the main effects of the three factors are statistically significant, but not their two-way interaction. The study found that the process is not only to improve pedal body machining capability and process sigma level, but also to improve the cost of poor quality (COPQ) and reduce the scrap percentage. The scrap percentage was reduced from 0.53% to 0.44% for an average of six months.

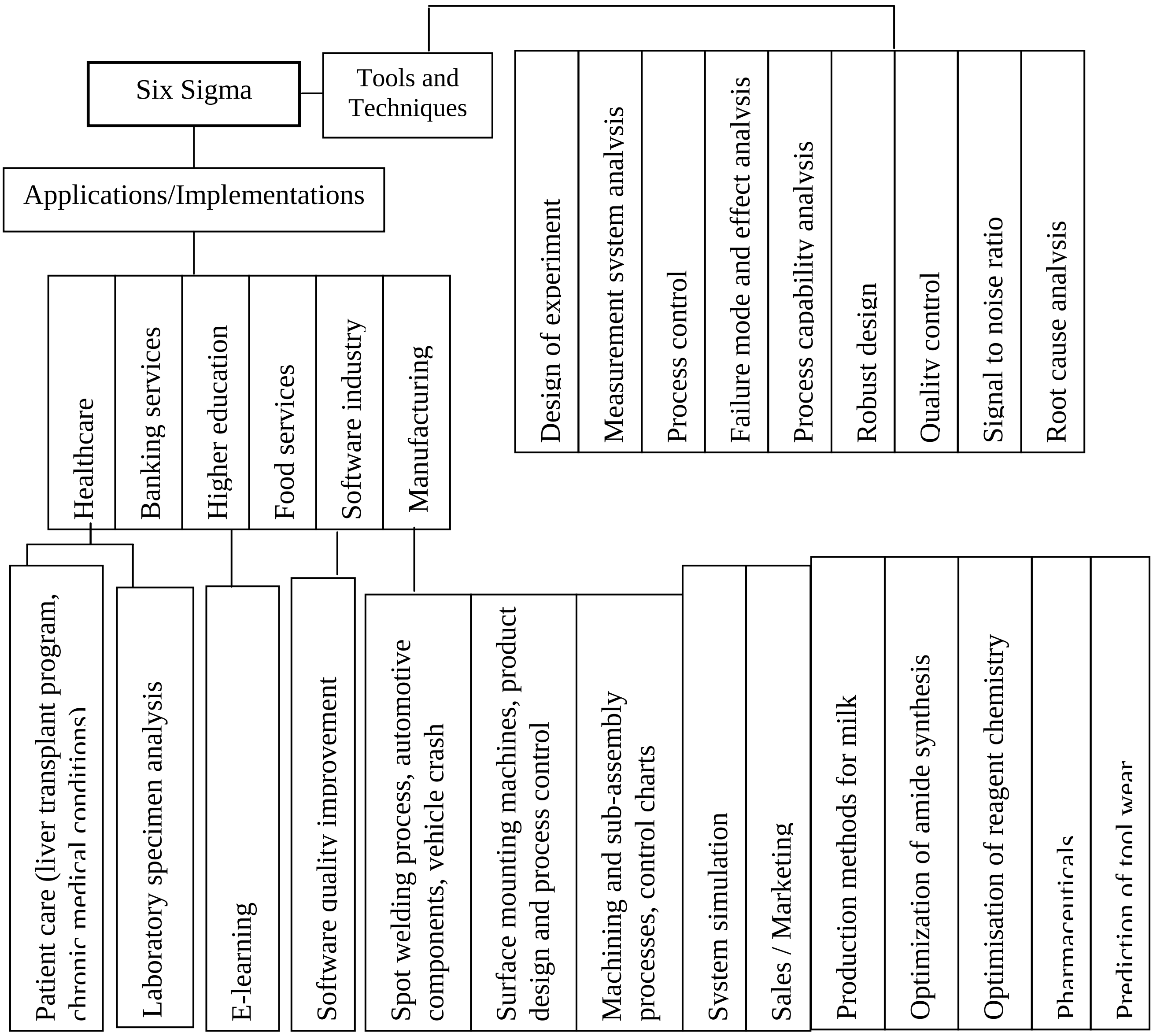

Figure 4: Example of a Six Sigma framework: methodologies and applications/implementation

The project also proved that Six Sigma improvement methodology is applicable in manufacturing processes.

2.4 Six Sigma in the service sector

2.4.1 Six Sigma in healthcare

A wide range of research has been conducted on Six Sigma applied to the various other aspects in the healthcare delivery system: direct care delivery, administrative support, and financial administration. Examples of beneficial Six Sigma projects in healthcare are included in Table 2. Other important areas of the application of Six

Sigma in healthcare include improving antibiotic timing [29] and emergency department activities in a hospital [35], the incidence of catheter-related bloodstream infections in a surgical unit [19], improving hand hygiene, producing timely and accurate claims reimbursement [28], streamlining the process of healthcare delivery, and reducing the inventory of surgical equipment and related costs [52, 61]. Hill *et al* [29] report on a national surgical infection prevention (NSIP) project that provides quality tools and measures to improve surgical patient safety in the USA. Measures include antibiotic administration within one hour of incision, and appropriate antibiotic choice.

The historical data revealed a 37% compliance with surgical prophylactic antibiotic timing, and a 67% compliance with correct antibiotic selection. A team for antibiotic timing and antibiotic choice in surgery (ATACS) was formed, and it utilises that methodology: define, measure, analyse, improve, and control. The team's objectives were to improve antibiotic delivery from 37% to 90%, targeting an administration time of 30 minutes prior to incision, and to improve prophylactic antibiotic selection compliance from 67% to 95% by a specified date. Antibiotic timing compliance improved 162%, from 37% (Mean = 71, SD [Standard deviation[= 34, N = 64) to 97% (Mean = 27, SD = 11, n = 87) (P = 0.000). Compliance with correct antibiotic selection was improved by from 67% (36/52) to 97% (82/84) (P = 0.000). Preventing process failure was demonstrated by decreased risk scores.

Supply chain management	Billing accuracy	Insurance denials
Documentation	Human resources	Inventory control
Patient satisfaction	Care coordination	End of life care
Speed and accuracy of admissions	Accuracy of lab results	Surgery scheduling
Emergency department patient flow and cycle time	Laboratory and radiology cycle time	Antibiotic administration
Referral authorisation	Billing, coding and reimbursement	Bed availability

Table 3: Examples of Six Sigma project initiatives in healthcare organizations (Modified from Sehwail and De Yong [56])

Frankel *et al* [19] use Six Sigma methodology to address the catheter-related bloodstream infection (CR-BSI) rate, which considerably exceeded the USA nationally-established median over a nine-year period (see Figure 5).

They hypothesise that use of Six Sigma methodology would result in a substantial and sustainable decrease in the CR-BSI rate. Compared with historical controls, adoption of chlorhexidone-silver catheters in high-risk patients had a considerable impact (50% reduction, $P < 0.05$). The authors conclude that the study represents the first successful application of a Six Sigma corporate performance-improvement method to impact on purely clinical outcomes. CR-BSI reduction was substantial and sustained after other traditional strategies had failed.

Mary and Wing [43] describe the sigma project spear-headed by a number of top managers, such as trust chief executives and unit general managers. It involves 16 sites and nearly 30 individual initiatives at those sites. The region has provided pump-priming funding. By going for a fault-free service and getting it right first time, large productivity gains are being made. Since delays in obtaining laboratory results can have a direct impact on appropriate diagnosis, timely treatment and an overall length of stay for patients in the emergency departments of hospitals were ensured.

Improve

Standard operating procedure changes

What?	Why?	When?
• Catheter tip culturing	Verify safety of wire change from PA catheter to triple lumen	4.2001
• Switch to daily dressing change	Dirty wound site high risk	5/2001
• Standard operating procedure for wire change o Double gloving o Use of pre-assembled kit o Assistant to remove outer gloves	Procedure associated with infection	9/2001
Specific attention to sterile field • Pre-assembled kits for wire changes and new line insertions	Easier to do the 'right thing'	12/2001
• Change in documentation	Illustrate practice to providers	1/2002
• Training video shown consistently	Promote practice standardisation	2/2002
• Antibiotic coated catheter	New 'x' of CR-BSI	11/2002

Figure 5: Six Sigma action plan for decreasing catheter-related bloodstream infection rate at Yale New Haven Hospital (Source: [19])

Woitas and Willemsen [62] improve the laboratory test turn-around time (time of order to the availability of test results) by applying a seven-step Six Sigma process to determine where the greatest opportunity for improvement exists in the emergency department of a hospital. The pre-data showed that the major delay was between the time of the laboratory order and the time when the blood was obtained (an average of 22.3 minutes). A new method incorporating criteria-based blood draws was implemented, which reduced the order-to-results time from an average of 45 minutes to an average of 15 minutes for patients meeting the criteria. Future research should address differences in treatment and outcomes for ED patients using this criteria-based system, changes in efficiency and work flow of ED care, and length of stay, and also assess patient, nurse, physician, and laboratory staff satisfaction.

2.4.2 Six Sigma methodology in 3M [66]

In recent times, 3M, a giant company in the computer industry, has become one of the world's major adopters and proponents of Six Sigma methodology. The company has demonstrated that Six Sigma could lead to higher quality output, increased productivity, and energised employees. Today, records available in the public domain indicate that more than 30,000 employees have been trained in Six Sigma, with plans to complete GreenBelt training for all salaried employees. Globally, over 11,000 projects have closed and more than 12,000 projects are currently underway. Apart from implementing Six Sigma within the organization, 3M has demonstrated the need to assist their customers in developing creative solutions for their business and manufacturing challenges. Hundreds of 3M industrial business-customer Six Sigma projects have been accomplished. Here, three examples are given of a major automotive manufacturer, a well-known food producer, and a leading manufacturer who had quality problems. The automotive manufacturer had a significant challenge with its largest-selling vehicles. 3M assisted in using Six Sigma to provide a cost effective solution in a short time frame. The well-known food producer needed to keep track of the product that its makes and ships. In the event of a product recall, it needed to locate every food item shipped, right down to the hour it left the production line. With the assistance of the 3M Six Sigma project, 3M-developed packaging management software, and a Six Sigma control plan. 3M applied Six Sigma methodology, together with the in-house team of a leading manufacturer, to solve a quality issue with one of its needed product designs.

2.4.3 Six Sigma in finance

Kwak and Anbari [37] report that the Bank of America (BOA) is one of the pioneers in adopting and implementing Six Sigma concepts in order to streamline operations, attract and retain customers, and create competitiveness over credit unions. With several hundreds of Six Sigma projects in the areas of cross-selling, deposits, and problem resolution, BOA reports a 104% increase in customer satisfaction and a 24% decrease in customer problems after implementing Six Sigma [53]. American Express applied Six Sigma principles to remove external vendor processes and eliminate non-received renewal credit cards. The top management of other financial institutions, including GE Capital Corp., JP Morgan Chase, and Sun Trust Banks are also using Six Sigma to focus on and improve customer requirements and satisfaction [53].

2.4.4 Six Sigma in the software industry

In the software industry, Hong and Goh [31] address some common misconceptions on the potential of Six Sigma in software, as well as some actual practical challenges. A framework is suggested both for top managers and practitioners and for managers interested in exploiting the benefits of statistical analysis in general, and the Six Sigma statistical process in particular.

2.4.5 Six Sigma in research and development

Successful stories of Six Sigma implementation in research and development target the reduction of project cost, increased speed to market, and the improvement of research and development processes. In a survey conducted by Johnson and Swisher [34], only 37% of respondents had formally implemented Six Sigma principles in their research and development organization. Rajagoplan *et al* [50] report that the development and manufacturing of a new prototype in a refining industry (W.R. Grace) was reduced from between 11 and 12 months to between 8 and 9 months by implementing the design for Six Sigma (DFSS) method. A graphical representation of the conceptual benefits and improvements of implementing Six Sigma in research and development is shown in Figure 6.

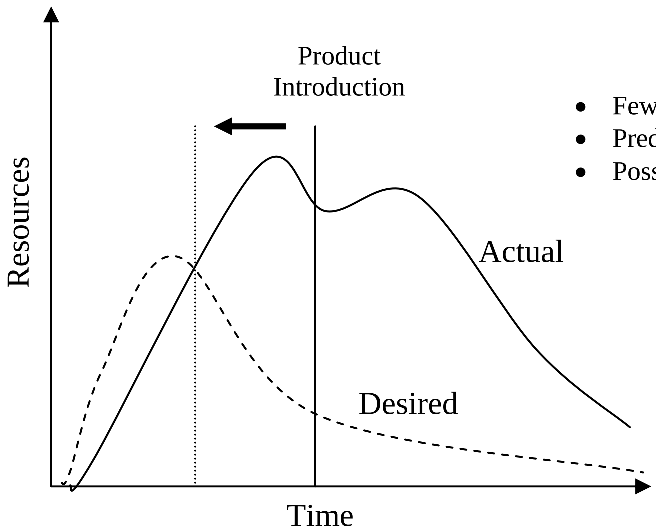

Figure 6: Advantages of applying Six Sigma in research and development projects (Source: [34])

2.4.6 Six Sigma in sales and marketing [65]

Sales and marketing functions are perhaps the most difficult organizational groups where the Six Sigma concept has been implemented. This difficulty stems from the fact that selling and marketing are not usually seen as business processes. This is particularly true of sales, where the sales process differs with each customer. It then becomes difficult to convince employees in the sales and marketing department of the organization to embark on a Six Sigma project so that their sales target can be achieved. Despite this problem, there is much room for applying Six Sigma tools in sales and marketing. Even at the sales representatives' level, back-office processes and administrative work could be tremendously improved by applying the Six Sigma concept. In marketing activities too, excellence in managing product promotions and developing trade information could be achieved with the application of Six Sigma.

In sum, Rath and Strong [65] suggest a number of projects where Six Sigma could be applied in sales and marketing activities. These include (i) development of methodologies that would optimise sales force allocation, (ii) development of a framework that would minimise sales promotion cycle time, (iii) investigating how Six Sigma could be applied to increase response rate for direct mailings, and (iv) investigating an improvement methodology for the conversion rate of proposals into actual projects.

3. CRITICAL VARIABLES AND SUCCESS FACTORS FOR SUCCESSFUL IMPLEMENTATIONS OF SIX SIGMA PROGRAMMES

There are numerous critical variables and success factors that could assist top management in understanding the benefits for an organization that is planning to implement Six Sigma. In the points below, pitfalls and lessons to be learnt from the previous experiences of organizations are outlined.

1. Progress in Six Sigma implementation is best achieved by linking Six Sigma practices to projects. These projects allow multi-disciplinary team members to collaborate and create opportunities for individuals and organizations to grow in knowledge, team spirit, etc.

2. Effective communication among the various teams is essential. This relates to disseminating notices of meetings, and passing on vital information on processes and other issues that would assist in achieving the Six Sigma goals.

3. For any new project to be carried out, an assessment of the equipment status and needs should be done so that necessary additional facilities may be obtained on time without having any negative effects on project completion time.

4. There is nothing as bad as operating a process whose basics you do not understand. Thus it is essential that every person in the organization understands customer requirements, and has a general idea of how the process will assist in satisfying the customer.

5. Teach Six Sigma by example. Constitute a multi-functional group that will be responsible for Six Sigma documentation. Commission the group to produce reports or documents on process flow diagrams, product performance, appearance, finished products, and customer requirements.

6. Poor communication among members working on projects may result in one group accusing the other of handing over one job or another to them, or completely avoiding responsibility. Thus, a strong team could be constituted to improve communication. In constituting this team, it is essential to identify employees with strong communication skills. In unionised environments, union members who hold publicity responsibilities may be useful for this assignment. Communication should also be improved within and beyond the company. The communication group should seek to disseminate information on the ongoing Six Sigma project to vendors, and improve company relationships with it. A pitfall to avoid is discouraging good communication among team members working on Six Sigma implementation.

7. Top management commitment is a key success factor in the implementation of

Six Sigma. Such commitment manifests in top management's regular attendance at meetings, encouraging team members to be committed to work, and emphasizing the need for goal achievement in employees' tight schedules. Top management should remove obstacles such as the unavailability of funds for entertainment during meetings, and ineffective communication by top management in meeting schedules. Removal of such obstacles would encourage team members through having lasting experiences in the projects they participate in. Also, top management should make the effort to involve the employees. Six Sigma should be taught by example.

8. In companies where other programmes such Total Quality Management (TQM), Quality Circles (QC), Quality Function Deployment (QFD), etc. are currently operating, experts and consultants from outside the organization should first be invited to study the processes and advise the management on the implementation approach to adopting Six Sigma. The integration of Six Sigma with other quality cultures in the organization should be well-managed, particularly where conflicting goals are noticed.

9. In implementing Six Sigma projects, the advantage of expert opinion within the organization must be used. Naturally, there may be some team members willing to provide tips and information in solving Six Sigma problems. Such individuals' knowledge must be fully utilised for high quality decision-making.

10. Since team members are required to spend time on Six Sigma projects, it is important to engage compatible team members in the Six Sigma team. Preferred members are those who cherish teamwork and are committed to team progress. Also, the willingness of team members' bosses to release them for meetings should be obtained, particularly if members are from different divisions of the plant.

11. There should be established rules and policies relating to availability for Six Sigma project team meetings, and these should be enforced by the management.

12. Other initial success factors are: (i) It should be noted that Six Sigma may not be an easy or automatical solution for quality problems: its success depends on the efforts put into the Six Sigma process; (ii) the use of charts, posters, and bills is essential in teaching team members and employees in general where and how Six Sigma could be used; (iii) from time to time project teams should seek help from management, and if need be, from outside the organization.

13. Since implementing a Six Sigma project may involve setting up teams, top management should understand the following: (i) Team membership is very important. The skills, strengths, and weaknesses of employees should be considered in placing members in teams. For example, union executives who do publicity may possess strong communication skills, which would be useful for disseminating project communication. Such employees should be highly rated and selected for teams responsible for communicating ideas and

information to people within and outside the organization. (ii) The structure of Six Sigma project meetings is very important. For each team, decisions on who presides at meetings, what to discuss, and the time frame for meetings should be carefully specified. (iii) Team leaders should seek to maximise the involvement of both members and people outside the team so as to obtain the best level of Six Sigma practice in the organization. (iv) In disseminating information on the importance and use of Six Sigma in organizations, consideration should be given to easy-to-understand charts, posters, and bills. Such communication tools foster a better understanding and deeper commitment of employees in the organization.

14. Well-planned and implemented training courses, which will first be handled by outside experts and then by in-house experts, should be carried out for the various categories of employees. Courses designed for beginners, intermediate, and advanced employees in Six Sigma knowledge are essential. All team members should be trained, and their cooperation in ensuring successful Six Sigma implementation is essential. The aim of training is to develop a knowledge organization.

15. In constituting team members for Six Sigma project, group strength (or being in a conglomerate of companies) is an advantage. However, the limitation of team members having to travel great distances to meet frequently should be considered. The ability of team members to work independently is essential.

16. Since experience in implementing other quality programmes such as Quality Function Deployment (QFD) would help in the easy adaptation of Six Sigma programmes, it is suggested that organizations seeking to implement Six Sigma should first ensure a successful implementation of QFD before embarking on specialised programmes such as Six Sigma.

4. CONCLUSION AND FUTURE DIRECTIONS

High quality products are becoming weapons in this age of market competitiveness in the global market. In this paper, a survey of the literature is undertaken with a view to identifying the various research thrusts on Six Sigma. However, in implementing Six Sigma in organizations, its penetration into the workforce and the task of gaining the commitment of the members of the organization is greatly helped if the organization has prior experience in the implementation of any quality initiative such as Quality Function Deployment (QFD). In addition, it has been emphasized that the commitment of the top management is essential to progress and goal attainment in Six Sigma projects. It should also be noted that rules and policies need to be enforced in order to achieve results under the condition of meeting datelines.

Based on the results of this study, it is concluded that there are still many opportunities for the application of Six Sigma by top management. The Six Sigma area needs significant attention in modelling problems in different areas of application. From the literature review, the modelling aspect of Six Sigma application is still growing. However, it is expected to mature with the contributions of other researchers from related disciplines. Future researchers may need to focus on modelling the implementation process. Such a model should be expanded to cover the quality performance of an organization during management transition and changeovers. An important research question could be, 'What would be the effect of mergers and acquisitions when an on-going Six Sigma implementation process coincides with a change of ownership of the organization concerned?' Another important modelling problem is the issue of cost. We may be interested in knowing what the implementation cost of Six Sigma would be in one period relative to another for small, medium, and large organizations. The effect of inflation on funds provided for the implementation process is also worth researching. Charts could be provided with indices for the various industrial categories indicated.

Through an extensive literature search, it was observed that very little documentation exists in the application of Six Sigma to engineering education. In one case, it was limited to statistics education. Clearly, Six Sigma researchers have many questions to answer. Some of these are: (i) How do we apply Six Sigma to the university training of engineers to ensure quality control in graduates? (ii) What about the use of Six Sigma in controlling the quality of research undertaken by university lecturers?

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