DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF
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A LITERATURE REVIEW ON SIX SIGMA

by
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İZMİR

A LITERATURE REVIEW ON SIX SIGMA

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We have read the thesis entitled **“A LITERATURE REVIEW ON SIX SIGMA”** completed by **YİĞİTCAN ÇELİKOĞLU** under supervision of **PROF. DR. G. MİRAÇ BAYHAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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A LITERATURE REVIEW ON SIX SIGMA

ABSTRACT

In this study, the roots, historical development, theoretical background, and future expectations of six sigma quality improvement approach, which emerged in manufacturing industries in the mid 1980s, are analyzed within the framework of an academic literature review. In this context, firstly the historical developments of quality phenomenon in the Western World, Japan, and Turkey are explored, and the theoretical basis of this quality system is identified. Then, the academic journals covered by Science Citation Index (SCI) Expanded are searched without time limits with keyword "six sigma". Almost all of the articles in the resulting set are examined in full-text; and a comparative statistical analysis is conducted. This analysis is based upon factors that are derived directly from the contents of the articles. Analysis results are used in order to determine the current situation, up-to-date trends, and historical transformations in the literature, therefore the implementations of six sigma. The results are discussed in detail and ideas about the future implementations of six sigma are given.

The literature study shows that although no consensus is built up on either the definition or the implementation of six sigma, it is believed that it will maintain its importance in the following years.

Keywords: Six sigma, quality improvement, literature review.

ALTI SİGMA ÜZERİNE BİR LİTERATÜR ARAŞTIRMASI

ÖZ

Bu çalışmada ilk uygulamaları 1980'lerin ortalarında imalat sanayiinde görülen altı sigma kalite iyileştirme yaklaşımının kökenleri, tarihsel gelişimi, teorik arkaplanı ve geleceğine dair düşünceler, bir akademik literatür araştırması çerçevesinde incelenmiştir. Bu bağlamda önce kalite olgusunun Batı'daki, Japonya'daki ve Türkiye'deki tarihsel gelişimi ele alınmış; altı sigma ve bu kalite sisteminin ardında yatan teorik temeller ortaya konmuştur. Bunları takiben SCI Expanded kapsamındaki tüm akademik dergiler tarih kısıtlaması olmaksızın "altı sigma" anahtar sözcükleriyle taranmıştır. Elde edilen sonuç kümesindeki makalelerin tamamına yakını tam metin olarak incelenmiş ve karşılaştırmalı bir istatistiksel analize tabi tutulmuştur. Bu incelemelerde tamamen makalelerin içeriklerinden elde edilen faktörler dikkate almıştır. Elde edilen sonuçlar ile, altı sigma literatüründe ve dolayısıyla uygulamalarındaki mevcut durum, güncel eğilimler ve tarihsel değişimler belirlenmiştir. Bu sonuçlar detaylı olarak tartışılmış ve gelecekteki altı sigma uygulamalarıyla ilgili fikir yürütülmüştür.

Yapılan literatür çalışması neticesinde altı sigma kavramının ne tanımı, ne de uygulamaları üzerinde ortak bir görüş oluşmamış olduğu tespit edilmekle birlikte altı sigmanın önümüzdeki yıllarda önemini koruyacağı düşünülmektedir.

Anahtar sözcükler: Altı sigma, kalite iyileştirme, literatür araştırması

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CHAPTER ONE
INTRODUCTION

Every organization has objectives. A non-profit organization seeks to generate societal values while a company tries to maximize its profits. All organizations have to use certain resources, such as human labor, money, and time, in the creation process of the products to meet their objectives. When producing virtually any product; including goods, services, information and so on; every organization "wants" to use less resources and create more products. In other words, every organization wants to be more productive, in order to be closer to their objectives. Quality is an important factor for productivity. Firms striving in a highly competitive environment have to take quality into account.

Military organizations were the first to take the concept of quality into account. Commercial firms followed them. As the widespread use of the concept in Japan brought market domination in a relatively short period of time like 30 years, Western world, especially companies from the United States, had to take the issue more seriously. In the contemporary world, where competition is the main characteristic of the business environment, the productivity and therefore quality are usually a matter of life and death.

As the quality concept gained importance, academic interest on the subject grew. Beginning with Shewhart, followed by many others, statistical sciences were embedded into the concept. In this way; multitudinous tools, rule-of-thumbs, academic approaches, and standards were developed. Some of them became generally accepted principles, while some of them became milestones fallen into disuse. Based on these developments, the quality concept was systematized and became a vital part of conducting business.

The subject of this study, six sigma[1], is probably the last chain of this process. Being first formulated and used in the industry in early 1980s, six sigma became a step in revolutionizing the scope and use of quality systems in business today. With six sigma's emphasis on perfection and comprehensive character, being bolstered by success stories of industry leaders, it became a benchmark quality management system. Today six sigma is a quality management system adopted by at least 25% of the Fortune 200 firms (Hsieh, Lin, & Manduca, 2007). Besides anecdotal success stories, objective criteria show the success of six sigma as well: Howell (2000) suggests that "six sigma company shares do better than the Dow Jones blue chip average". Such a popular business concept would naturally open up its commercial area. Countless consultancy firms were established and countless six sigma "experts" sprang up.

Despite the big impact of six sigma on industry, the academic community lags behind in its understanding of six sigma (Linderman, Schroeder, Zaheer, & Choo, 2003). The commercial part of six sigma outpaced the scientific part. Academic contributions related to six sigma, which reside in the framework of this study, give a better insight to this argument. Organization of the study is as follows:

In Chapter 2, the roots of the six sigma are considered. Going back in the history of quality, the conditions which made advances in quality field possible and necessary are analyzed. In this way, a historical and political-economic perspective is utilized, and the emergence of six sigma is associated with the sociopolitical developments in the world.

In the following chapter, an introduction to six sigma is provided. Basic information about the six sigma methodology is given and Define – Measure – Analyze – Improve – Control cycle, which is unique for six sigma, is presented. The underlying theory is depicted briefly in this chapter.

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[1] A registered trademark of Motorola.

In the fourth chapter, the academic literature related with six sigma is analyzed in detail. Science Citation Index Expanded[2] is searched and all bibliographic information is investigated together with the full-text articles available. No time limits were set; therefore the whole literature (covering years between 1991 and 2007) is reviewed. The goal of this study is to find trends in academic literature, and to determine its contributions on six sigma. Both bibliographic data (like date, geographical location, keywords, etc.) and data derived from full text articles (like success factors, definitions, challenges, etc.) are evaluated. For the analysis, Microsoft Excel 2007 software was used.

In the last chapter, discussion and conclusion, the results of the literature review are summarized, future research areas are recommended, and trends in the literature which are identified in the previous chapter are discussed considering their effects on the future of six sigma and quality profession. In this chapter, it is argued that six sigma is not perceived in consistently among persons concerned. Two definitions, two practices, or two practitioners of "so-called" six sigma might sometimes be considerably different. Moreover, academic studies related with the issue are very few when compared with huge amounts of "best practice" studies, articles acting as an advertising medium, and widespread interest. As the subject proves itself being a real standard, it will be discussed more, studied academically more, its perception will thus be homogenized like some other quality systems -such as TQM or ISO- or otherwise as it becomes an advertising slogan in the weekly magazines, the positive conviction towards six sigma will disappear in the course of time.

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[2] Trademark of The Thomson Corporation.

CHAPTER TWO
HISTORY OF QUALITY

The history of six sigma is in fact the history of quality. To discuss this concept, technical developments in this field should be reviewed together with the historical conditions that made these developments possible and necessary. Without such historical perspective, the achievements and the connections between them are unlikely to be grasped totally. In this respect, the advances in quality will be discussed in two time periods, until and since the beginning of 20^{th} century; and in three geographical areas, Western World, Turkey, and Japan. In this study, Western World refers to the United States of America (the US) and Europe.

2.1 Quality Prior to Statistical Quality Engineering

Although quality as an engineering issue is a subject of a time period starting with 19^{th} century, to say that the history of quality "dates back to the beginning of civilization" (Maguad, 2006) should not be considered as an exaggeration. "Search for the better" has always been an issue of human beings and communities.

As the most primitive concern of quality, separation of the adequate from the inadequate has been a widely used method since ancient times. It can be easily seen in the article from the Code of Hammurabi: "In case a house built by a construction craftsman collapses because of the inadequacy of his skills and the owner of the house dies; the construction craftsman will be sentenced to death." (Bozkurt, 2003). Even in primitive societies, separating eatable food from the uneatable can be an illustration of testing and inspection.

In the First and Middle Ages, the division of labor induced craftsmanship. Craftsmen were performing all the tasks in a production sequence. Before being recognized as craftsmen, the producers had to accomplish the apprenticeship period and prove to be trained adequately. The quality of the product was evaluated by both the Government and the Craftsmen Guild, which established detailed specifications for production processes and materials, and methods of inspection and testing (Maguad, 2006). In this state of civilization, quality was an integral part of production.

The Industrial Revolution, taking place in the mid-1700s in Europe, made a great impact in the production methods. Wide use of mechanical power led to a new phase of mass production in which quantitative aspect of production gained importance against the qualitative aspect. According to Radford (1922), this era was characterized by the demand for "maximum production," for quantity or volume of manufactured goods. With the lowering cost of production, and increasing accessibility of the lower classes of the population to goods and services, a middle class is formed. Since increasing consumption put the emphasis to the quantity of production in the factory, quality was no longer the foremost priority (Maguad, 2006). Unlike the craftsman who was in a constant effort to produce better products, the factory worker had to produce according to the standards. Juran said that interchangeability of parts and standardization brought by the growth of technology and interstate commerce required greater precision throughout machinery, tools, and equipment (Maguad, 2006).

The necessity of international standards showed up with the increasing foreign trade. In 1904, a conference was gathered in the US for discussing standardization studies and in 1906, International Electrotechnical Commission was formed and assigned with the task of determining necessary international standards (Ruppert, 1956).

2.2 The Era of Statistical Quality Engineering

Quality in the first phase of Taylorist factory production was handled by inspectors who reported to departmental production supervisors (Maguad, 2006). In his book considered as the publication that effectively began the statistical quality control (SQC) era (Maguad, 2006), Radford (1922) suggests a “form of management or direction which establishes the quality requirements and then sets up the organization and selects the personnel capable of securing that quality".

According to Juran, the following changes in the market environment put quality assurance efforts through a transformation: "(a) Greater complexity and precision of products, (b) threats to human society and health, and to the environment, (c) government regulation of quality, (d) the rise of the consumerism movement, and (e) intensified international competition in quality" (Maguad, 2006). In this phase, quality of products needed to be assured before they meet customers, and this uniformity required certain statistical methods. This led to the emergence of the concept of statistical quality engineering. Goh (1999) describes statistical quality engineering as the application of a collection of data-based techniques to improve and sustain the performance of industrial processes or products.

In fact, statistical quality engineering can be traced back to early 19th century, when a German mathematician Carl Frederick Gauss (1777-1855) introduced "sigma" as a measurement standard, as well as the concept of the normal curve or distribution (Raisinghani, Ette, Pierce, Cannon, & Daripaly, 2005). However, Walter Shewhart, a mathematician with Ph. D. and a practitioner who spent his professional career at divisions of AT&T (Western Electric and Bell Telephone Laboratories) used this concept in real-life manufacturing environment after more than a century (Besterfield, Besterfield-Michna, Besterfield, & Besterfield-Sacre, 2003). It was two years after the publication of G. S. Radford's book "The Control of Quality in Manufacturing", when in 1924, Shewhart brought up the statistical control chart concept, which is generally considered as the beginning of SQC (Montgomery, 1991). He introduced three sigma as a measurement of output variation and his three sigma concept was deemed adequate for most manufacturing organizations until the early 1980s (Raisinghani et al., 2005).

Toward the end of 1920s, Dodge and Romig, both of Bell Telephone Laboratories, developed statistically based acceptance sampling as an alternative to 100% inspection. By the middle of the 1930s, statistical quality control methods were in wide use at Western Electric, manufacturing arm of the Bell System, although the value of the subject was not generally recognized by the industry (Montgomery, 1991).

World War II gave impetus to quality concerns. Military production necessitated certain quality characteristics. An illustration of growing quality concern is the establishment of American Society for Quality Control in 1946 (Montgomery, 1991). International Standards Organization (ISO) was established in 1947, right after the war. When the war finished, losing parties' top priority was to reconstruct their economies and to overcome the destructive effects of war while the winning parties were striving to maintain their strong position in economy. Hobsbawm (1996) notes that the US economy enlarged enormously during the World War. It did not experience any war-related damages, besides it also increased its gross national product significantly. Gross domestic product of the US was five times that of Japan by the year 1950.

2.2.1 Statistical Quality Control in Japan

Quality concerns had a different meaning in Japan. When Japan surrendered in 1945, Japanese industrial plants were largely destroyed by American bombings. It was urgently necessary to export goods in exchange for imported foodstuffs. (Nixon, 1962). This was not possible with their reputation for making cheap and shoddy imitations of existing products (Nixon, 1962), similar to today's China. Therefore, after World War II, Japanese manufacturers, as the citizens of a country whose right to determine policy and invest in arms industry was taken by prevailing parties of World War II, (Hobsbawm, 1996) had to hold a completely different path on quality. Quality was "of vital concern because of the need for increased export of manufactured goods to pay for needed imports of food" (Koyanagi, 1951).

When it comes to quality in Japan, one has to mention a Japanese organization, whose history is inseparable from the history of quality in Japan. The Union of Japanese Scientists and Engineers, JUSE, was a half-politicized professional organization formally established in 1946. It pioneered the study of quality control in Japan immediately after the war. Economic reconstruction was discussed in JUSE from the scientific side during and after the war and JUSE leadership was aware of the potential importance of its members to the country's economic recovery. JUSE leaders, during their works realized that the SQC methods utilized in the Western World was the most promising field for the upturn of their economy (Tsutsui, 1996). A "Quality Control Research Group" was formed and 39 professionals were trained by professors for a month in 1949 (Koyanagi, 1951). Translated foreign materials, including Shewhart's works, were used as course texts. The course proved so successful among corporate engineers and managers that it was repeated on a larger scale in 1950 (Tsutsui, 1996).

Koyanagi (1951), the Managing Director of JUSE then, notes that the first step in SQC was the translation of E. S. Pearson's book on SQC in 1942. However, it did not make a big impact because the military demanded largest possible production volumes during war, without any concern in quality (Koyanagi, 1951). In the wake of the war, The Industrial Division of the Civil Communications Section of Mac Arthur's headquarters was charged with rebuilding the shattered infrastructure. In 1949 and 1950, three American officers taught a series of intensive eight-week management seminars for the top executives and technical staff of Japanese electronics manufacturers (Tsutsui, 1996).

In 1950, Edwards Deming, perhaps the most famous quality expert/guru in the world today, was invited to Japan by JUSE to lecture some training courses on SQC. Deming lectured a course of eight days to 330 engineers. The lecture notes of this course were printed and sold 5700 copies. When Deming refused the royalties[3] from the sale, JUSE set up the Deming Prize for "outstanding work in theory, or in application, teaching, or dissemination; and in addition, citations to one or more manufacturing plants or corporations that have made notable progress in application during the past year" (Koyanagi, 1951). This was the time when the name Deming was inseparably associated to quality movement in Japan (Tsutsui, 1996). In that

[3] A total of $727 (Tsutsui, 1996)

visit, Deming attended a dinner with 50 leading executives of Japanese manufacturing industry. This was followed by an all-day meeting with 60 other top executives (Nixon, 1962). In the meetings and courses during his visit, Deming was successful to make Japanese engineers and executives believe in the value of SQC. The Deming Prize[4], which was "acknowledged as the premier accolade in corporate Japan and became a source of considerable publicity for JUSE" (Tsutsui, 1996), also increased the interest in the field, and a kind of "quality campaign"[5] started.

Following Deming's visit in 1950, JUSE organized basic and advanced-level SQC courses and continued publishing a monthly periodical on SQC, which then became the guide of the practitioner (Koyanagi, 1951). In 1951, Deming was invited to Japan again. He addressed 440 engineers with his 8-day courses, and met 60 other top executives in an all-day meeting (Nixon, 1962).

By the year 1951, Japanese industrialists were having problems with the mathematical complexity of SQC techniques. In 1954, a former employee of Western Electric from 1924 to 1941 who visited Japan in response to JUSE's invitation, Joseph Juran suggested considering QC an integral part of the production process, a tool of management rather than a statistical veneer. Juran's intervention had finally provided the impetus and direction for a major reevaluation both JUSE and the practitioners were looking for (Tsutsui, 1996). Juran is known with his contribution about management involvement in all levels to quality assurance efforts (Besterfield et al., 2003).

Juran visited Japan in 1960 again. By the year 1962, there were 7000 statistically trained quality engineers in Japan. A series of courses were presented on TV. 100,000 copies of the Deming booklet were sold (Nixon, 1962). Tsutsui (1996) defines the transformation of Japanese quality as follows:

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[4] In 1951, the prize money summed only $150, apparently a symbolic amount (Koyanagi, 1951).

[5] It was so popular that American companies also rivaled for the prize. Texas Instruments was the first American corporation that received a Deming Prize, in 1985 (Bozkurt, 2003).

"Between 1955 and 1965, Japanese quality control was transformed from a narrow specialty, the obscure sorcery of progressive engineers, into a far reaching, comprehensive framework for making Japanese factory management more systematic and scientific. This new synthesis came to be known as Total Quality Control" (Tsutsui, 1996).

This fast development affected Japanese economy positively. After 1965, Japan increased its exports at a much higher rate when compared to the US. The 1960s witnessed sharp increases in the number of Japanese patents, the number of researchers, and research expenses (Statistics Bureau of Japan [SBJ], n.d.). Japan became a world-class supplier, especially in high-technology manufacturing.

Table 2.1 Comparison of American and Japanese products in the 1970s and the 1980s

Quality of Automobiles	**TGWs (things gone wrong) in first 8 months per 100 cars**	
Chrysler	285	
GM	256	
Ford	214	
Japanese (avg.)	132	
Toyota	55	
Quality of Semiconductors	**US Companies**	**Japanese Companies**
Defective on delivery	16%	0%
Failure after 1000 hours	14%	1%
Quality of Room Air Conditioners	**US Companies**	**Japanese Companies**
Fabrication defects	4.4%	<0.1%
Assembly line defects	63.5%	0.9%
Service calls	10.5%	0.6%
Warranty cost (as % of sales)	2.2%	0.6%
Quality of Color TVs	**US Companies**	**Japanese Companies**
Assembly line defects per set	1.4	0.01
Service calls per set	1.0	0.09

Russell and Taylor (1998) gave place to a comparison of American and Japanese products in the 1970s and the 1980s as it is shown in Table 2.1. A great difference in product quality is present in the figures. This dramatic difference in the quality would have an effect on the US manufacturers. Japan had already changed the reputation of low quality shoddy imitation manufacturer to a high quality, high technicality producer with unique products.

2.2.2 Economy in the Western World

Between years 1950 and 1970, daily life in rich world completely changed. Refrigerators, private washing machines, telephones, etc. became ordinary elements of life. Technology enhanced and size of products diminished. Research and development activities became important for economical growth. Cost of developing a new product became an integral and important part product cost. Finished goods output worldwide quadrupled during 1950 and 1970. The trade of finished goods increased by 10 times (Hobsbawm, 1996). However, this "American dream" did not last forever. The oversized situation of the American economy limited the growth rate when compared to others, especially Japan (Hobsbawm, 1996).

Speaking for quality practices, after World War II, the interest on quality could not maintain the acceleration because of the perspective suggesting quality as something necessary in the war time (Bozkurt, 2003). Western manufacturers in 1950s and 1960s had developments in quality assurance such as the emergence of quality costs and reliability engineering concepts, and the emergence of the viewpoint that quality is a way of managing the organization (Montgomery, 1991). Feigenbaum, with the publication of his book "Total Quality Control" in 1951, made a contribution to the quality subject emphasizing the importance of preventive activities against firefighting (Bozkurt, 2003). He argued that quality begins by identifying the customers' requirement (Besterfield et al., 2003). In 1950s designed experiments were first introduced in the US. However, widespread utilization of these methods was relatively slow until the late 1970s, when many Western companies discovered that their Japanese competitors had been systematically using them (Montgomery, 1991).

The Japanese influence in the US market was most effectively experienced during the oil crisis in 1973. When the American consumer was questioning the rising costs of fuel consumption due to the oil crisis, introduction of fuel efficient Japanese Honda Civic had a drastic effect in American automobile market (Hobsbawm, 1996).

At that time, ordinary American had to explain this kind of failure. An economy which is said to be superior to its competitors, especially Soviet way of economic system, was being challenged by a country who was atom-bombed 30 years ago by the US. At the first thoughts, it was widely believed that "culture" was Japan's secret weapon[6] and that societal differences precluded the adoption of Japanese management models in the US (Tsutsui, 1996). However, early rationalizations that the Japanese success in manufacturing was a cultural phenomenon were disproved by the "Quasar event". Matsushita purchased a failing television plant of Motorola in Quasar with a contract binding her to retain the entire hourly workforce of 1000 people. After two years, with the identical workers, half the management staff and little or no capital investment, Matsushita had doubled production, had cut assembly repairs from 130% to 6%, and reduced warranty costs from $16 million/year to $2 million/year (Russell & Taylor, 1998). Japanese way of conducting business and gibing quality the top-most priority proved successful.

Two things occurred in the early 1980s increased the pressure on American manufacturers to revise the way they are conducting their business: (1) Introduction of mass produced miniature electronics such as transistor radios and televisions, i.e. microelectronics revolution (Gollomp, 2005); and (2) introduction of Japanese electronics into foreign and American markets. The lower price and higher quality of the Japanese goods made these imports attractive to the global consumer (Raisinghani et al., 2005). Figure 2.1 shows the increase of TV receiver exports of Japan, especially in the early 1980s, which can be attributed to the high quality of Japanese products.

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[6] Deming himself clearly expressed his appreciation of Japanese culture open for lifelong learning without barriers (Nixon, 1962).

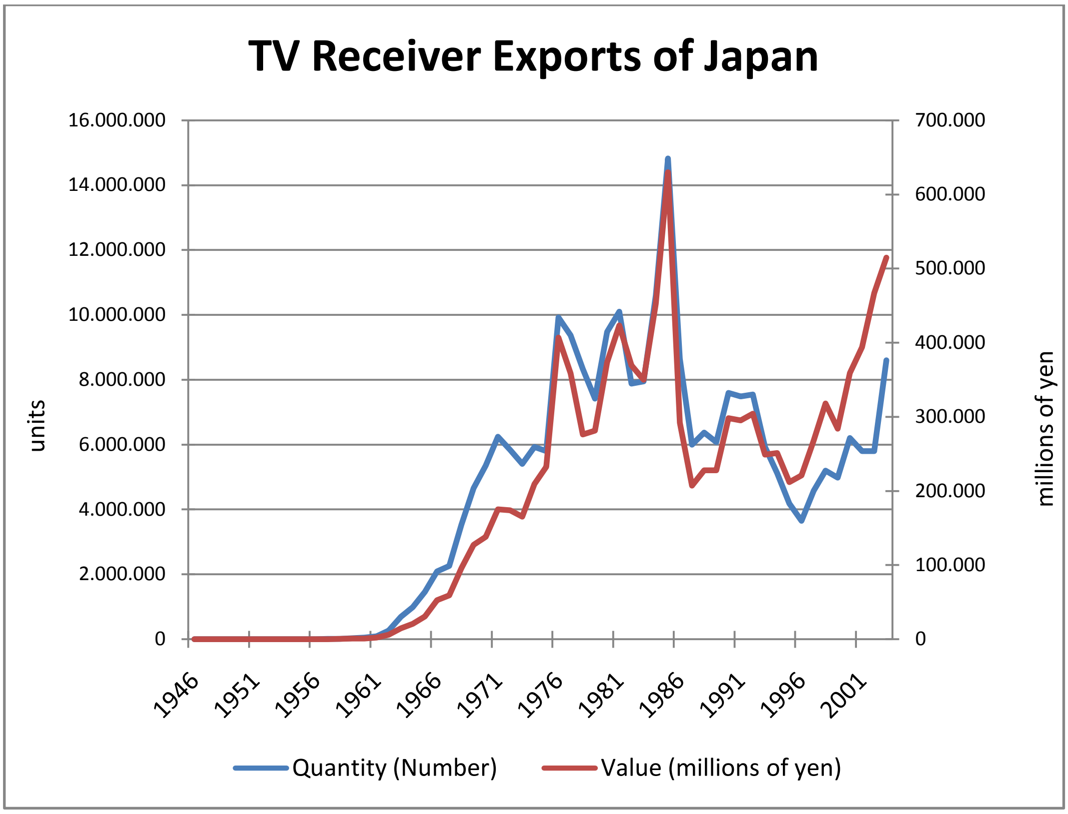

Figure 2.1 TV Receiver exports of Japan (SBJ, n.d.)

In response to the Japanese threat, several quality initiatives were introduced in 1980s. "Quality Circles" at Honeywell, "Zero Defects" at Ford Motors, and "Total Quality Management" at Boeing and Bell Telephone can be mentioned. MBNQA was instituted to encourage quality efforts (Raisinghani et al., 2005). ISO 9000 quality system standards were published in 1987 (Devlet Denetleme Kurulu [DDK], 2004). In late 1980s, quality was discussed in every function (finance, sales, human resources, maintenance, management, manufacturing, and service) of organizations (Bozkurt, 2003). However, no initiative was as successful and as popular as six sigma in answering the threat in the field of quality.

2.2.3 Six Sigma's Emergence

In the early 1980s, Motorola, an American microelectronics producer, was at risk of losing its semi-conductor business to Japanese competitors (Hahn, Hill, Hoerl, & Zinkgraf, 1999) because of the conjuncture discussed previously. Mikel Harry (1998), one of the first practitioners of six sigma techniques and writer on the subject, highlights that in 1981, Bob Galvin, the Chairman of Motorola, challenged his company to achieve a tenfold improvement in performance over a five year period.

Bill Smith, an engineer of Motorola was studying the correlation between a product's field life and how often that product had been repaired during the manufacturing process. In 1985, Smith concluded that if the product was assembled error free, the product rarely failed during early use by customer (Harry, 1998). This was consistent with Philip Crosby. In his book *Quality is Free* published in 1979, he had argued that "doing it the right the first time" is less expensive than the cost of detecting and correcting nonconformities (Besterfield et al., 2003). Bill Smith also marked the concept of "rolled throughput yield". He developed tools and techniques that evolved into being six sigma methodology later (Rath & Strong Management Consultants, 2005). Mikel Harry was another engineer studying variation in Motorola. He was the first one who went on to refine a methodology and call it *Six Sigma* (Rath & Strong Management Consultants, 2005). The studies on variation paid off in a short time in Motorola. The uniqueness of their quality initiative was the active participation of the managers, including the CEO Bob Galvin (Eckes, 2005). When the inaugural Malcolm Baldrige National Quality Award was won by Motorola[7] in 1988, six sigma attracted public attention it deserved.

Larry Bossidy, a former General Electric (GE) executive under Jack Welch, left his company and took the CEO position in AlliedSignal. Bossidy had conversations with Galvin and decided to put six sigma in use in his company which was then not in a good position in the market and in customers' views. In three years, the company saved millions of dollars by virtue of the six sigma program.

McClusky (2000) argues that six sigma was starting to fade away when reengineering phenomenon became popular. Still, AlliedSignal's success in six sigma drew attention of Jack Welch, Bossidy's former CEO and mentor. When

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[7] Motorola was to receive second MBNQA in 2002, thanks to its six sigma projects (Raisinghani et al., 2005).

Welch requested a seminar on the changes in AlliedSignal for his colleagues –during a golf match- Bossidy accepted. Although Welch could not attend the seminar himself due to his hearth surgery, he decided to make six sigma a corporate initiative in 1995 (Eckes, 2005). This decision and personal dedication of Welch in the program brought superior financial success to GE. Six sigma had official support and active participation of managers. General Electric happened to be the most successful organization that used six sigma for productivity and efficiency. After 2 years, General Electric had saved $320 millions. Consequently, six sigma turned out to be one of the most popular and prominent management philosophies.

In several years, hundreds of organizations decided to adopt six sigma as their management strategy. Still there are multitudinous firms that are in the decision/implementation phase and many others providing them with consultancy service.

2.3 Quality in Turkey

The development of quality in Turkey possesses different characteristics before and after the introduction of Turkish Republic. Therefore, the history of quality in Turkey will be reviewed in two parts.

2.3.1 Ottoman Empire Era

The Ottoman economic activities depended largely on implements of war, food and textile industries. Majority of the organizations were either agricultural or textile-oriented. Indeed, the textile industry, combined with the strict supervision of *ahi* system was far ahead of the foreign competitors (Muluk, Burcu, & Danacıoğlu, 2000). Quality concept in the pre-Republic era was first seen in *ahi* system seen in 13^{th} century. *Ahi* organizations were craftsmen's professional organizations which promoted cultural and ethical values, and were responsible of assuring the quality of products produced by their members. Later, they were transformed into guilds, like those in the western countries (Muluk et al., 2000). Baer (1970) says:

> "Control of the quality of goods made or sold by artisans and merchants was one of the main tasks of the guilds. …. Governments used guild system as an instrument for supervising the implementation of its instructions in respect …. The guild was supposed to be alert to detect fraudulent practices and goods of inferior quality."

The first published document about quality during Ottoman Empire was "Kanunname-i İhtisab-ı Bursa" (Bursa Municipal Law), which regulated textile standards of Bursa silk clothes, bearing the date 1502. This document is regarded as the first-known standard of the world (Türk Standartları Enstitüsü [TSE], 2007). During 1520 and 1644, standards related to textile materials were published (Muluk et al., 2000).

While the Industrial Revolution brought high development rate in the western industrialization, the capitulations[8] in the Ottoman State limited the development of domestic manufacturers. These two factors together made the Ottoman economy lag behind western world in commercial, economic, technological, and industrial aspects (Muluk et al., 2000). Quality could never gain priority in such an environment. Çizakça (1980) says that Ottoman cloth producers faced with intense foreign competition took the course of lowering production costs. He says that "the court registers are full of documents pertaining to attempts by desperate clothiers to circumvent guild regulations and reduce the quality of their cloth". Thus the guilds became dysfunctional in this process. Against the foreign competition, the Ottoman State granted *gedik* rights in order to protect domestic producers by the 17th century, in 1727 formally. Those craftsmen who were granted *gedik* rights held the monopoly of producing their products while the others were forbidden to produce. Monopolistic production lasted till mid 1800s and finally in 1913, guilds and *gedik* rights, which were practically inapplicable, were formally dismissed (Cin & Akgündüz, 1989).

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[8] Commercial rights given to foreign countries. The first was given to France in 1532 by Sultan Suleyman.

Meanwhile the Ottoman State tried to promote modernization and industrialization in order to cope with the international system. With the Administrative Reforms in 1839, the State gained new roles in public services. This increased the need for scientific and accurate data, and as a result, The Department of Statistics was established (Muluk et al., 2000). This was the first state organization related to statistics. With "Bab-ı Ali İstatistik Encümeni Nizamnamesi", statistics studies were defined by legal code (Türkiye İstatistik Kurumu [TÜİK], 2007).

Industrialization attempts were made in the Second Constitutional period (1908-1918) by Jeune Turc movement which pursued a "national economy policy", but the World War I barred Turkish industrialization. Although Ottoman Empire could never reach to the development rates of the West, especially after 1839, Western style of mass production started to grow in Anatolia (Muluk et al., 2000).

As the brief history suggests, from 1299 to 1923, the seeds of quality can be seen in the practices of Ottoman Empire. However, these efforts could not reach to the level in the Western world (Muluk et al., 2000), in the lack of an industrialist urban middle class as that in Western Europe.

2.3.2 Quality in Turkish Republic

The Turkish Republic, founded upon an Independence War in 1923, inherited a primitive industrial infrastructure and zero-level industrial activity. Izmir Economy Congress was gathered in 1923 in order to discuss the development route of the Turkish economy in the following years. With this Congress, capitalistic development way was selected for sure and the industrialization of the new state was decided to be planned and supported by the state itself in the absence of the capitalist class (Muluk et al., 2000). The state was going to play an active role in providing the environment in which a new bourgeois class could develop and realize economic development in cooperation with foreign capital (Boratav, 2003).

The 1920s were relatively unsuccessful in this respect due to two reasons: Firstly, international restrictions on custom tariffs introduced by Lausanne Peace Treaty; and secondly, the fact that the state undertook the indirect function of encouraging private investment but the newly emerging bourgeoisie preferred the short term profits by imports in this period (Boratav, 2003) Still, certain steps were taken. Meanwhile in 1926, Central Department of Statistics was formed (TÜİK, 2007).

Following the removal of restrictions of Lausanne in 1929, and in an attempt to avoid the negative consequences of 1929 world economic crisis, protectionist policies started to be implemented. Foreign trade policies of the state included tighter control over import and export goods (Boratav, 2003). In 1930, control standards for export goods were defined by law (DDK, 2004).

Statist economy policy soon complemented protectionism. Codifications of 1932 marked the beginning of an active role of the state in the industrialization (Boratav, 2003). The period between 1932 and 1950 were the years when modern basic industrial facilities were established in Anatolia (Muluk et al., 2000). Government-owned enterprises established in this period served as the backbone of Turkish industry for long years. The First Five-Year Industrialization Plan was prepared and put into practice in 1934. The aim was to make the country stand on its own feet, establish the heavy industry and public works like transportation, communication, irrigation systems etc. As a result of this plan, considerable advances were made in the industry. Sümerbank, Etibank, and approximately 20 other factories were opened. Post-1929 crisis environment was seen as an opportunity (Devlet Planlama Teşkilatı [DPT], 2006).

However, the Second Five-Year Industrialization Plan could not be effectively practiced because of the war economy before the World War II. From 1939 to 1945, the labor force and the consumption diminished. This phenomena obstructed advances in industrialization, consequently quality (Muluk et al., 2000).

After World War II, a Congress on Industry was gathered in 1948. In this congress, the principle of state control was abandoned. The decision of integration with Western capitalism within the cold war context determined the course of Turkish industry in the forthcoming years. In 1950, investment of foreign capital was set free for the sake of accelerating industrialization. After 1950 statism was completely abandoned (Muluk et al., 2000).

Integration with the world economy and liberalization brought in an interest in productivity and quality. In 1953, National Productivity Center (MPM) was formed. Although the main motive was the need for increase in the productivity, quality issues were also handled by the Center. In 1954, Union of Chambers of Turkish Engineers and Architects (TMMOB) was formed. TMMOB had an important role of uniting engineers and defending their professional rights just like their counterpart in Japan, JUSE. TMMOB played a role in certification efforts. In the same year, Turkish Standards Institution (TSE) was formed under the Union of Chambers of Commerce and Industry. In the following year, TSE was accepted to ISO and in 1956 to IEC. TSE was established with a separate identity by law in 1960. This was an important step in the history of quality in Turkey, since when the authorities of the institution were clarified and quality was encouraged systematically from then on, the interest in quality subjects grew evidently. Translation of some books on quality illustrates the increasing interest. TSE collected 19 thousand standards for the beginning and this is the basis of the current archive (DDK, 2004).

The rise of national developmentalism and import-substitute industrialization in the world, together with the sociopolitical changes in Turkey after 1960, opened a new path in Turkish industry. The leaders of the Coup d'etat in 27th of May, 1960 blamed the unplanned structure of the economy for economical problems and a central planning organization was established. State Planning Organization (DPT), which was regulated in the 1961 constitution, led the planned development era in Turkish economy. Development Plans were prepared for five-year periods, first of which started in 1963. With the First Development Plan, standardization and quality control studies were attached importance (DPT, 2006).

With a law in 1967, the production, sales, import and export of goods which fail to meet the standards are forbidden. Increased interest on quality issues resulted in the translation of important books on quality-related subjects. This process gained speed in the 1960s (Muluk et al., 2000).

The Second Development Plan (1968-1972) promoted improving quality control studies, although it did not impose the establishment of new quality facilities like laboratories. Chambers of engineers under TMMOB started quality certification for goods related to their fields (Muluk et al., 2000). Standards for basic industrial goods and export goods were completed during the period covered by the Third Development Plan (1973-1977). MPM gave more importance to quality subjects in the 1970s. Symposiums and seminars on the subject were held (Muluk et al., 2000). TSE started certification by gibing TSE mark in 1964 (DDK, 2004).

Economic depression in Turkey in 1977-1979 marked the end of the national developmentalist model. The following development plans were to bear the impact of transition to neoliberal economy (Boratav, 2003). Turkey's increasing integration with the competitive world economy brought up quality issue. The Fourth Development Plan (1979-1983) was the period when the most effective decisions about quality were made. SQC became widespread by the support of the Government. The Scientific and Technological Research Council of Turkey (TÜBİTAK) was charged with the establishment of a Metrology Center. TSE's authorities were determined precisely by the law bearing the date of 1983. This promoted quality certification in the industry. The number of firms certified by TSE[9] between 1970 and 1989 is shown in Figure 2.2 (Muluk et al., 2000).

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[9] Please note that after 1983, the figures represent the number of firms who had the right to use TSE or TSEK marks. The slight drop in this year is due to this alteration.

Figure 2.2 Number of Firms that Received Quality Certificates from TSE

Figure 2.2 indicates that with the Fourth Development Plan, especially after the authorities of TSE were clarified, certification gained wider acceptance in the industry (Muluk et al., 2000).

Open trade policy and export-oriented production was necessitating better quality performance. Therefore the first examples of quality initiatives were seen in export firms, firms operating in highly competitive environments and firms with foreign partners. The 1980s witnessed the first uses of quality initiatives. In 1982 Turyağ started establishing quality circles, followed by Otosan and Koç Holding in 1983 (Muluk et al., 2000).

During the Fifth Development Plan (1985-1989), modern quality control techniques in the industry were to be encouraged and training programs were to be promoted. Addressing international markets highlighted cost and standardization problems. Therefore, in order to avoid material, labor, energy, and time loss, proactive and integrated quality control techniques were supported. As productivity and quality gained importance, an organization for giving quality certificates harmonious with regional and international standardization became obligatory and Calibration Center of TSE was founded (Muluk et al., 2000).

TSE also started training programs on ISO in the late 1980s. TS ISO 9000 model, which was suitable for Turkey's conditions, was developed from ISO 9000 standard. TSE started certification of this standard in 1991 (DDK, 2004). It was 2002 when Turkish Accreditation Agency let third bodies give ISO 9000 accreditation (Türk Akreditasyon Kurumu, n.d.). Sixth Development Plan (1990-1994) aimed at increasing the number of Turkish standards (DPT, 1989).

In the 1990s, Total Quality Management (TQM) initiatives started in certain companies. The first successful initiative was seen in Brisa (Muluk et al., 2000). From then on, modern quality initiatives are tried to be implemented.

In 1991, Turkish Quality Society (Kalder) was founded. Kalder, which is a member of EFQM, is organizing symposiums, seminars and training courses, publishes books on quality and gives the National Quality Award (Kalite Derneği [KalDer], 2001).

During the Seventh Development Plan (1996-2000), manufacturing and service sectors were encouraged to use productivity techniques, particularly TQM. However, Eighth Development Plan says that these initiatives that promoted TQM and quality in general started to be carried out "by different organizations in different platforms". This shows that the government states its will to recede from central planning role. In fact, Eighth Development Plan (2001-2005) calls public and private sectors to join their quality efforts (DPT, 2000). In early 2000s, many public organizations such as Ministry of Education, some public hospitals (Çalışma ve Sosyal Güvenlik Bakanlığı, 2003), and several municipalities initiated TQM efforts by the help of Kalder and related private organizations (KalDer, 2001).

Besides the emphasis on private sector, the new world economy marked by growing internationalization and regionalization also pushed the governments to deal with the harmonization of internal and external standards. Turkish Accreditation Agency (TÜRKAK) was founded upon a law in 1999, in order to certify the conformance of domestic and international organizations and their products to certain standards (DPT, 2000). With the candidacy to European Union process, DİE was restructured as Turkish Statistical Institute in 2005 (TÜİK, 2007).

Today, many private companies adopted and integrated certain quality initiatives. Concerning the subject of this study, a selected list of the firms declared starting six sigma quality initiatives is as follows:

- Borusan Holding
- Ford Otosan
- Otokoç
- Demirdöküm
- Hugo Boss
- Sabancı Holding
- Aksa Akrilik
- TEI Tusaş
- Arçelik
- Eczacıbaşı - Vitra
- Petrol Ofisi
- Kalekim – Kalekalıp
- Erkunt Döküm
- Hayes Lemmerz International
- Delphi Automotive
- BSH
- Schneider Electric
- Medline

2.4 Timeline

A graphical display of the history of quality is given in Figures 2.3 and 2.4.

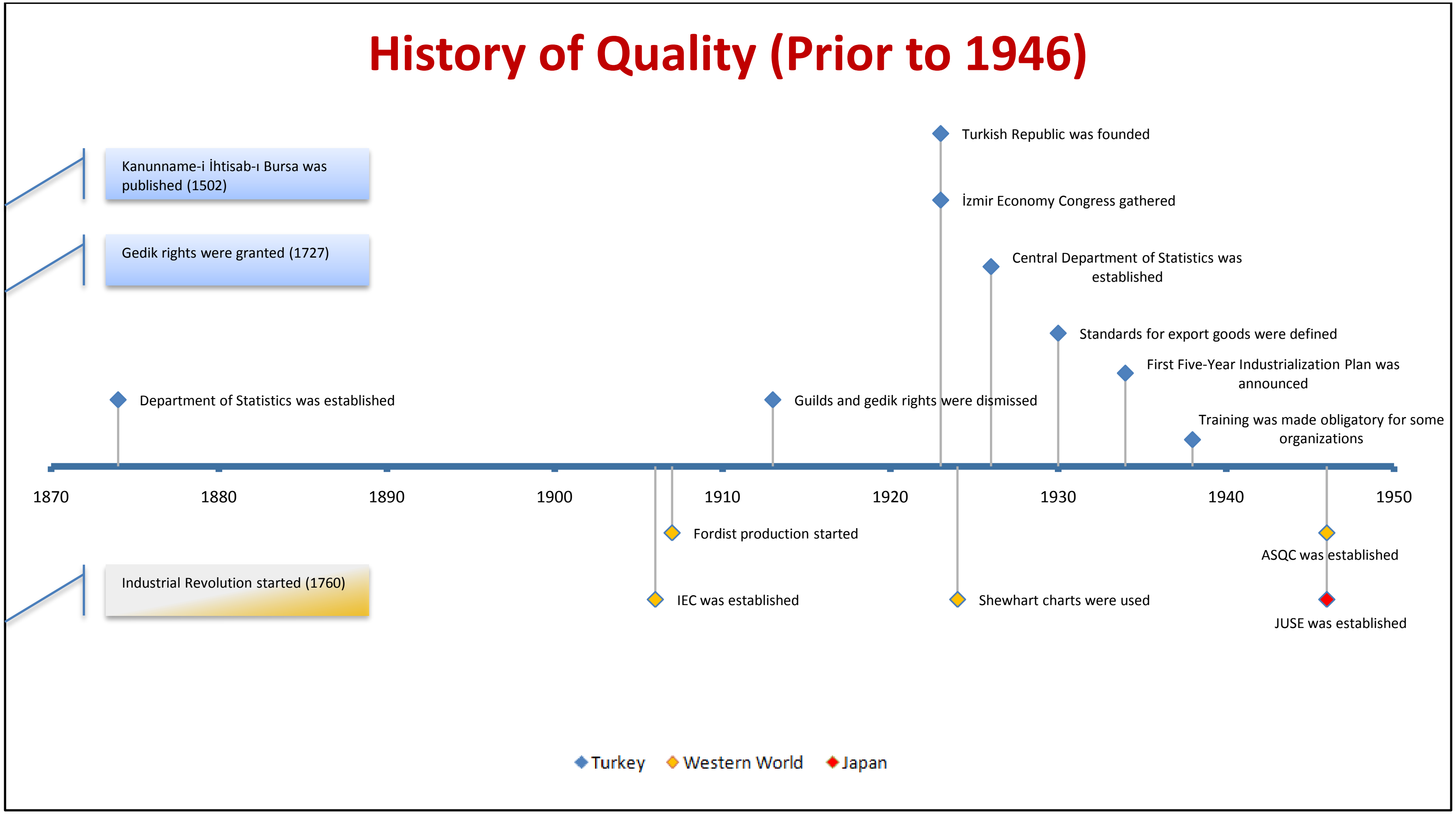


Figure 2.3 History of quality (prior to 1946)

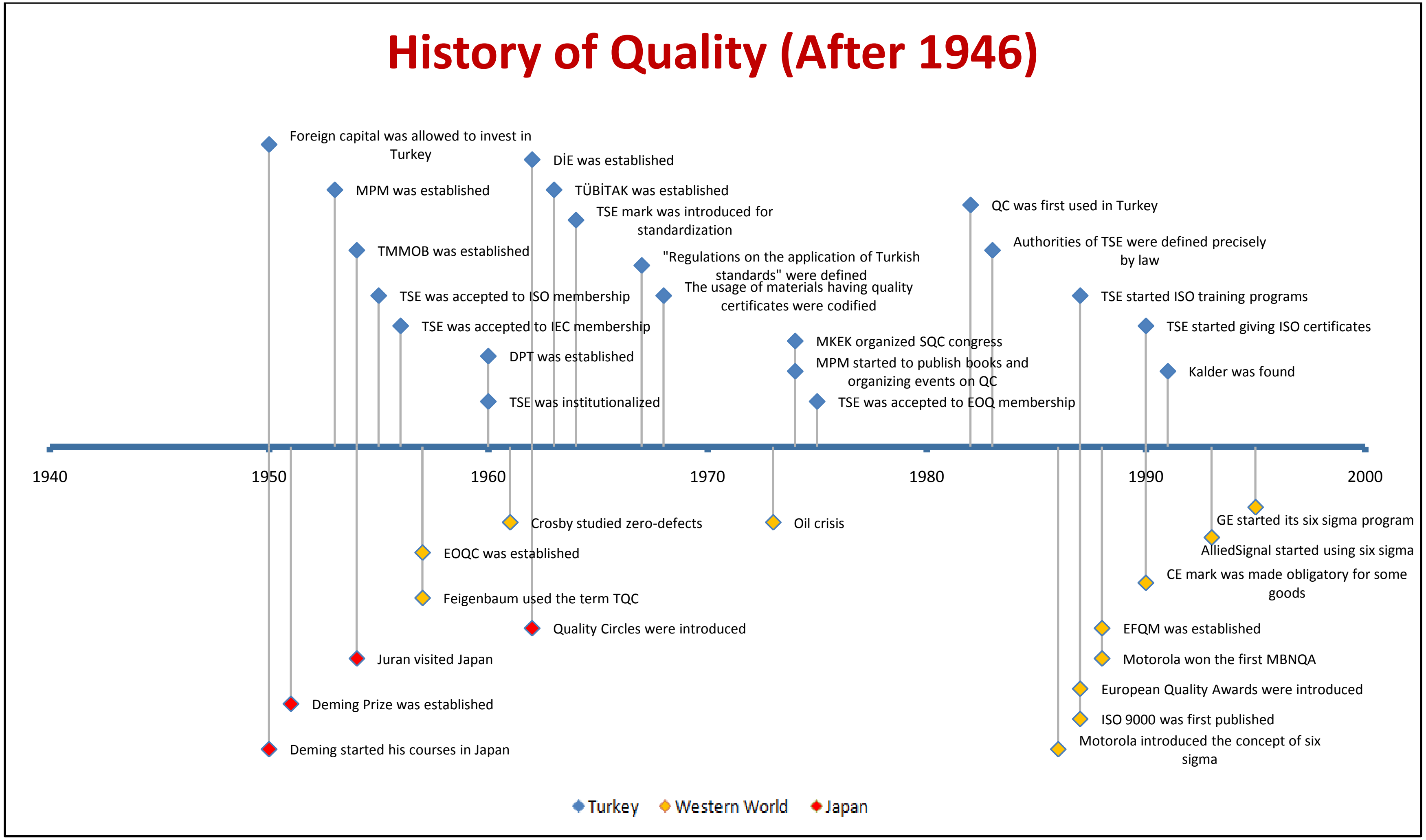


Figure 2.4 History of quality (after 1946)

CHAPTER THREE
BACKGROUND THEORY

This chapter aims at providing an introduction to basic six sigma concepts, underlying statistical theory and variation phenomenon, giving information about six sigma infrastructure, and listing how six sigma can help companies improve their bottom lines in different kinds of organizations.

3.1 Traditional 3 Sigma Limits

Neither traditional 3 sigma limits nor 99% success are not enough for today’s competitive environment. A process operated at 3 sigma level (without any mean shift) generates 99.7% acceptable yield. If process control limits were placed on a process capability curve, the control limits would be 3σ to the right and left of center. The area under the curve between two control limits represents the products or services conforming to specifications. In terms of defects, this capability level is equal to 2,700 defects per million opportunities (DPMO) (Harrold, 1999). The following figure adopted from Nevalainen et al. (2000) show how various processes necessitate certain quality levels.

As the figure shows, best in class companies produce at six sigma levels. For processes related with human life (e.g. airline fatality rate), even six sigma performance may not be enough. Most American companies are clustered in four sigma quality levels. The best products, however, are valued at six sigma, a level of excellence in performance that is truly world class (Harry, 1998).

Simple statistical calculations show that if with a 99% conformance, which is perceived as “almost perfect” by an average person, the following results would be experienced:

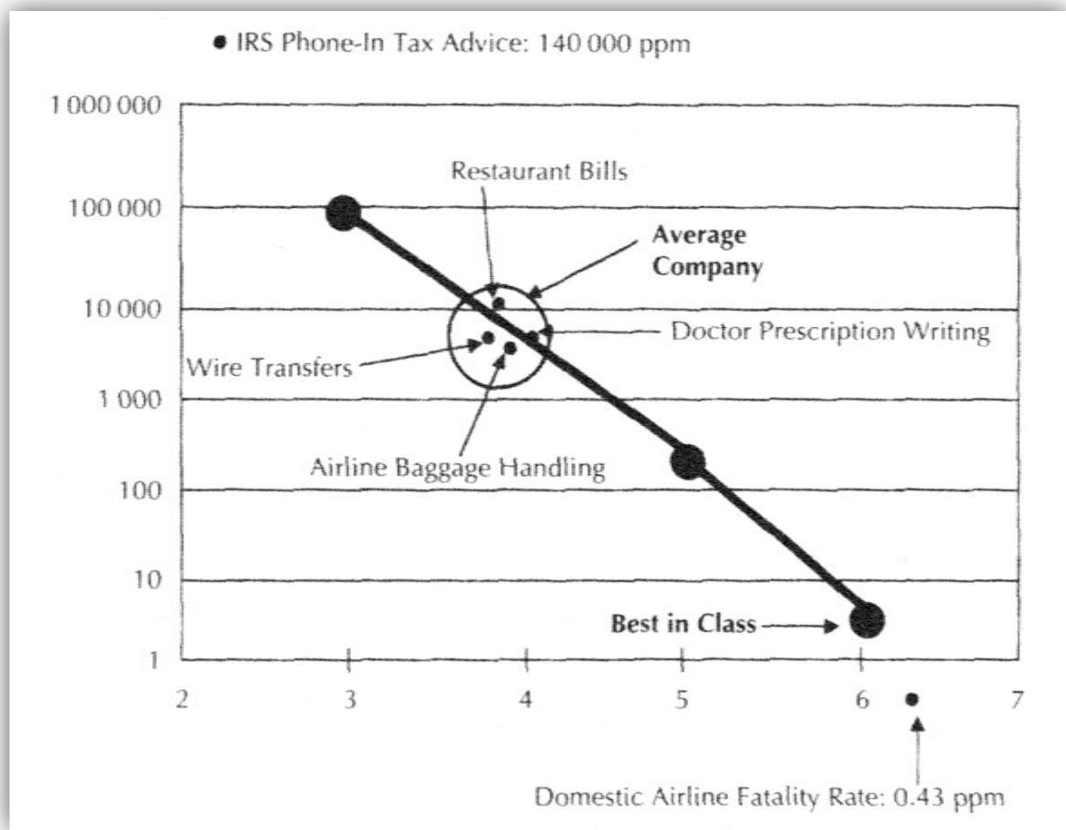


Figure 3.1 Quality levels of various processes

- 2 plane crashes in landing each day,
- 16,000 pieces of lost mail every hour,
- 500 incorrect surgical operations (deaths) each week,
- 7 hours without electricity, 1 hour with unsafe drinking water each month,
- 80 million incorrect credit card transactions in UK each year,
- 3000 newborns accidentally dropped by nurses each year.

On the other hand, six sigma aims at 99.9997% success rate, which makes only 3.4 parts per million opportunities be marked as defective. Six sigma is defined by Lee-Mortimer (2006) as a disciplined, measurement –based strategy for eliminating defects that focuses on systematic and project-based process improvement and variation reduction – driving towards achieving a process that does not produce more than 3.4 DPMO. Table 3.1 shows the number of DPMOs in various sigma levels.

Table 3.1 Sigma levels and related numbers of DPMO

Sigma Level	DPMO
1,0	697,672
1,5	501,350
2,0	308,537
2,5	158,687
3,0	66,807
3,5	22,750
4,0	6,210
4,5	1,350
5,0	233
5,5	32
6,0	3.4

Six sigma companies typically achieve faster working capital turns, lower capital spending as capacity is freed up, more productive R&D spending, faster new product development, and greater customer satisfaction (Harry, 1998).

3.2 Basic Six Sigma Concepts

Six sigma standard of 3.4 problems per million opportunities is a response to the increasing expectations of customers and the increased complexity of modern products and processes (Pyzdek, 2003), plus the developments discussed in the previous chapter.

The six sigma strategy measures the degree to which any business process deviates from its goal. Sigma, a letter in Greek alphabet, is used in statistics as a measure of variation. It represents the standard deviation of a “population”. It can be estimated using a “sample” of n observations with the following formula.

$$\hat{\sigma} = s = \sqrt{\frac{\sum(x-\bar{x})^2}{n-1}}$$

Six sigma deals with variation. Although no all-round definition for six sigma is reached by the academic or industrial community, every definition of six sigma builds upon the aim of reducing variation and thus saving money for the business.

The concept of variation has to be understood for a comprehension of six sigma. Makrymichalos, Antony, Antony, and Kumar (2005) say that variation is a fact of life and exists in all processes. It is impossible for a process to produce two perfectly identical products. However, variation is the main cause of quality problems. A typical manufacturing process is affected by many sources of variation: Raw materials, environment, human input, tooling wear, and so on (Fieler & Loverro, 1991). To improve quality, variation must be measured, reduced, and prevented (Goh & Xie, 2004).

Eckes (2005) notes that customers feel not the mean but the variation. For example, if a customer waits for his meal in a restaurant for 1, 5, and 24 minutes in his three visits respectively, the customer does not perceive that the mean service time is 10 minutes, but he/she thinks that the service time is highly variable. If a company cannot control the variation in its products or processes, it inevitably will lose customers. Therefore, reducing the variation in processes is the main goal of six sigma.

The importance of the variation present in a process is shown in the figure adopted from Lee-Mortimer (2006).

As the figure shows, in 3 sigma processes, defects, which are outside the specification limits, are far more frequent than in six sigma processes. As the number of defects increase, wasted operating costs and level of customer dissatisfaction increase (Harry, 1998). Six sigma studies would try to create a slim process curve, which peaks at the center.

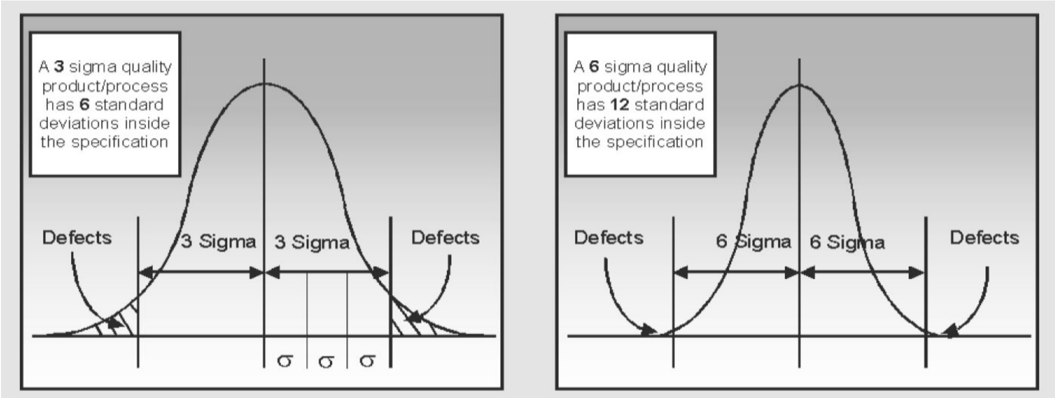


Figure 3.2 Comparison of 3 Sigma process and 6 sigma process

In practitioner literature, variation in a process is measured by capability indices. Processes with higher sigma capabilities get higher process capability index measurements. Therefore process capability analysis is a critical part of six sigma studies. Capability index C_p can be defined as the ratio of the design specification width to the normal variation.

$$C_p = \frac{USL - LSL}{6\sigma},$$

Where USL is the upper specification limit and LSL is the lower specification limit. For six sigma processes, C_p would obviously equal 2.0.

Research has shown that a typical process is likely to deviate from its natural center by approximately 1.5 standard deviations over a large number of production lots (Harry, 1998). This brings the necessity of another capability index, which tells about the proximity of the mean of the distribution to the target value. This index, C_{pk} is calculated as

$$C_{pk} = \min\left(\frac{USL - \bar{x}}{3\sigma}, \frac{\bar{x} - LSL}{3\sigma}\right)$$

For a six sigma process, C_{pk} is 2.0. However, when the 1.5σ shift is incorporated to calculations, C_{pk} becomes 1.5 where C_p remains 2 (Smith, 1993). With a perfectly centered process, the defect rate of a 6σ design is 2 parts per billion, but for the shifted process, the defect rate is 3.4 parts per million.

Reducing the number of defects per unit will also result in fewer early-life failures. This results in better customer satisfaction, and lower warranty and manufacturing costs.

Six sigma methodology considers the production as a process which transforms inputs to outputs and profit via a series of processes. Speaking generally, six sigma identifies process outputs (Y) and independent variables that affect process outputs (X), investigates Xs' effects on Ys, and determines tolerances in the Xs. In this way, six sigma translates an operational problem into a statistical problem; makes use of proven and widely used mathematical/engineering methods to solve it; and translates the results back to the practical actions (Pande, Neuman, & Cavanagh, 2004).

The final product of a production process carries certain characteristics, which determine the acceptability of the end product by the user. These critical attributes for customers are named *Critical to Quality* (CTQ). The identification of CTQ variables is one of the first steps carried out in a six sigma project (Lucas, 2002). Each time a fault that causes the process to fail to deliver what the customer wants with respect to product quality, delivery time or service, or failure to achieve the customer's CTQ, a *defect* occurs. Doble (2003) defines an action that has the potential to cause a defect as an *opportunity*. Having these descriptions clear, and taking 1.5σ shift into regard in processes, the "heroic" 3.4 DPMO goal of six sigma processes could make sense scientifically.

Six sigma's quality improvement means reducing waste by helping organizations produce products and services better, faster, and cheaper. Six sigma focuses on customer requirements, defect prevention, cycle time reduction, and cost savings. Thus, the benefits from six sigma affect directly the bottom line. Unlike cost-cutting programs which also reduce value and quality, six sigma identifies and eliminates costs which provide no value to its customers, waste costs (Pyzdek, 2003).

Maleyeff and Krayenvenger (2004) reminds correctly that the goal of 3.4 DPMO is placed on each CTQ, not on the final product. When a cellular phone with possibly thousands of opportunities could be found, expecting 3.4 defective phones per million is not a correct expectation. The following figure adopted from Smith (1993) shows the yield versus opportunities.

Complexity, parts/product	Yield, percent			
1	93.54	99.3	99.9	100.0
3	81.84	98.1	99.9	100.0
10	51.27	93.9	99.7	100.0
30	13.48	83.0	99.3	99.9
100	0.13	53.7	97.7	99.9
300	0.00	15.5	93.2	99.9
1000	0.00	0.2	79.2	99.6
3000	0.00	0.0	49.7	98.9
10 000	0.00	0.0	9.7	96.6
30 000	0.00	0.0	0.09	90.3
Robustness				
Std. deviations	$\pm 3\sigma$	$\pm 4\sigma$	$\pm 5\sigma$	$\pm 6\sigma$
C_p	1.00	1.33	1.67	2.00
C_{pk}	0.50	0.83	1.10	1.50
PPM	66 810	6210	233	3.40

Figure 3.3 Yield versus product robustness and complexity

Moreover, not all processes have to operate at the six sigma level. The appropriate quality levels of processes can be determined based on the strategic importance the cost of the improvement relative to the benefit (Linderman et al., 2003).

3.3 Six Sigma Methodology

More important than the technical definition is the concept of six sigma as a disciplined, quantitative approach for improvement –based on defined metrics- in manufacturing, service, or financial processes (Hahn et al., 1999). Six sigma reduces defects and improves CTQ measures via a systematic approach taken on a project-by-project basis (Goh & Xie, 2004). Problems are attacked by project teams using powerful quality and statistical tools in a structured and rigorous methodology. This process known as a simple performance improvement model is called DMAIC, as an acronym for Define – Measure – Analyze – Improve – Control cycle.

Figure 3.4 DMAIC cycle

At each step, certain statistical tools are applied to uncover root sources of variation. While the tools are not new, the six sigma approach adds considerable value to the use of existing tools. Its advantages include:

1. Providing an overall "roadmap",
2. Stressing the need to understand and reduce variation,
3. Emphasizing a data-based approach to management, versus gut feel or intuition,
4. Developing standardized vocabulary, metrics, and tools throughout highly diverse companies (Hahn et al., 1999).

These statistical tools and relative steps are discussed in detail in Section 4.18. In this section, the key processes in each of these steps are explained.

- Define
    - Six sigma project team is formed (Eckes, 2005),

- The problem is identified (Pande et al., 2004),
- Customer requirements and expectations are determined (Kwak & Anbari, 2006),
- Project boundaries and charter is defined (Kumar, Antony, Singh, Tiwari, & Perry, 2006).

- Measure
  - The problem/process is validated and detailed (Pande et al., 2004),
  - The value flow is documented, the process map is formed (Hsieh et al., 2007),
  - Process performance measures are set (Hsieh et al., 2007),
  - A data collection plan is developed (Kwak & Anbari, 2006),
  - Measurement system is validated (Doble, 2005),
  - Data are collected and compared to determine issues and shortfalls (Kwak & Anbari, 2006).

- Analyze
  - The causes of defects and sources of variation are analyzed (Kwak & Anbari, 2006),
  - Key input variables that affect the average and deviation of the measures of performance are determined (Hsieh et al., 2007),
  - Several key causes are defined and hypothesis are validated (Pande et al., 2004),
  - Desired goal is defined (Doble, 2005).

- Improve
  - Ideas are generated in order to eliminate root causes of variation (Pande et al., 2004),
  - Ideal settings for key input variables are determined (Hsieh et al., 2007),
  - Solutions are tried and standardized (Pande et al., 2004).

- Control
    - A strategy to monitor and control the improved process is developed (Kwak & Anbari, 2006),
    - Standard measurements are made for maintaining performance (Pande et al., 2004),
    - The measurement system is revalidated after the implementation of improvements (Doble, 2005),
    - Problems are attacked as they arise (Pande et al., 2004); action plans are made (Eckes, 2005),
    - Mistake proofing is made if applicable (Kumar et al., 2006).

Edgeman, Bigio, and Ferleman (2005) define DMAIC as a highly data-driven, fact-based application of the scientific method of inquiry that emphasizes discernment and implementation of the so-called “voice of customer” as related to processes, products and services that create value both for the producer and the consumer. Tools and techniques used in various phases include process mapping, process capability analysis, quality function deployment, failure mode effects analysis, statistical process control, pareto charts, scatter diagrams, fishbone diagram, brainstorming, and so forth.

The major elements of six sigma implementation are strong leadership, initial focus on operations, clear performance metrics, aggressive project selection, and selecting and training the right people. The initiative is driven by leaders at the highest levels of the organization –such as The CEOs of GE (Jack Welch), Motorola (Bob Galvin), and AlliedSignal (Larry Bossidy)- and permeates through all levels of management and operations (Hahn et al., 1999). For a successful implementation of six sigma and DMAIC, the following points should be carefully followed (Antony & Banuelas, 2002; Hahn, 2005; Pande et al., 2004):

1. Customer focus, emphasizing customer CTQs
2. Data and fact-based management
3. Process focus, management and improvement

4. Proactive management
5. Boundless cooperation
6. Search for perfection, tolerance to failure
7. Enthusiastic commitment of top management
8. Six sigma infrastructure
9. Involving everybody in an organization
10. Focusing on the entire system
11. Bottom line focus
12. Cultural change
13. Training
14. Project prioritization, selection, reviews, and tracking
15. Linking six sigma to business strategy
16. Linking six sigma to customers, suppliers, and human resources

Six sigma's timeline is usually very aggressive. Typically, companies look for an improvement rate of approximately ten-fold every two years, measured in terms of DPMO. Most companies with four sigma level operations adopt a five year six sigma goal (Harry, 2000).

Low hanging fruits (easy targets for low sigma performance organizations) can be collected and the effects of six sigma program on the budget can be felt in a very short time period. For example, for a standard four sigma company adopting a 5 year goal for reaching six sigma, Harry (2000) estimates that 78% of the improvements are realized at the end of the first year and 96% at the end of the second year. Reaching perfection for a company which has an ongoing and partly successful six sigma project is far more difficult than gaining striking savings for starters.

3.4 Six Sigma Applications in Various Sectors

Although six sigma has its origins in the manufacturing sector, it has room for application in various sectors. There is a growing recognition that six sigma is not just for the large US-based corporations who developed it, but is applicable to all types and sizes of company. There is nothing within the methodology that restricts its application (Lee-Mortimer, 2006). Six sigma can be helpful in various sectors as presented below.

3.4.1 Manufacturing

Reducing defects and preventing reworks are the main concerns in manufacturing environment. More reliable products, improved product quality, customer satisfaction, lower production costs and warranty claims are the anticipated results.

3.4.2 Service (General)

Success of six sigma in manufacturing sector drew the attention of quality experts in service sector. In fact, since all processes in service industry are interconnected in a system, exhibit variability, and create data that explains variability, six sigma is very suitable for service problems (Antony, 2006).

In service-related six sigma implementations, the type of the service being provided is important. For example, in a call center, Antony (2006) provides the following list of factors that can be critical for the customer satisfaction:

1. Greetings of service representative,
2. Accuracy of information provided to the customer,
3. Queuing time before the customer gets hold of an available representative,
4. Number of rings before an agent responds to the call,
5. Availability of past data about the customer,
6. Communication and comprehension skills of the representative,
7. Time taken to fix the issue.

The list can be enhanced with many similar factors. Six sigma can help understanding the processes which create these factors and minimize the variability in the products of these processes. Six sigma projects can identify the causes of defects, their impact on customers and their prevention methods.

3.4.3 Finance

In finance departments, typical six sigma projects can be (Kwak & Anbari, 2006; Antony, 2006):

- Improving accuracy of allocation of cash to reduce bank charges,
- Automatic payments,
- Improving accuracy of reporting,
- Reducing documentary credit defects,
- Reducing check collection defects,
- Reducing variance in collector performance,
- Reducing credit, statement, account opening, payment handling, etc., processing times,
- Reducing the number and duration of ATM breakdowns.

3.4.4 Healthcare

Zero-defect target of healthcare sector matches perfectly with the targets of six sigma philosophy. Typical healthcare projects may include (Antony, 2006; Raisinghani et al., 2005; Kwak & Anbari, 2006):

- Streamlining the process of healthcare delivery,
- Reducing inventory of surgical equipment and related costs,
- Reducing patient preparation and waiting times,
- Reducing diagnosis, medication and laboratory errors and improving patient safety,
- Increasing hospital bed availability.

3.4.5 Research & Development (R&D)

R&D departments are potential areas where six sigma projects can prove successful. Design for six sigma (DFSS) is used in more and more implementations every day.

Typical six sigma projects for R&D departments are as follows:

- Reducing product design costs,
- Reducing production lead time,
- Increasing speed to market new products.

3.5 Roles and Responsibilities of Six Sigma Participants

A very powerful feature of six sigma is the creation of an infrastructure to assure that performance improvement activities have the necessary resources. Six sigma makes improvement and change the full-time job of a small but critical percentage of the in-house technical personnel, and part-time job of the majority of employees. Six sigma uses a variety of improvement specialists to achieve its goals, often named in relation to *taek won do* titles. These specialists and their missions in six sigma organizations are discussed in Figure 3.5. The discussion is garnered from the studies of Harry and Crawford (2004); Hoerl (2001); Linderman et al. (2003); Pande et al. (2004); and Pyzdek (2003).

Figure 3.5 Six sigma roles and responsibilities

3.6 Six Sigma and Other Quality Initiatives

Six sigma can be compared to other quality initiatives in several ways. Below is a table bringing together the suggestions of Andersson, Eriksson, and Torstensson (2006); de Mast, Schippers, Does, and van den Heuvel (2000); Goh (2002); and Nave (2002).

Table 3.2 Six sigma and other quality initiatives compared

	Six Sigma	TQM	Lean	TOC	SPC
Theory	Reduce variation	Focus on customers	Remove waste	Manage constraints	Control processes
Method	DMAIC	PDCA	Identify value, identify value stream, flow, pull, perfection	Identify, exploit, subordinate, elevate, repeat	Control charts
Focus	Project/problem	Customer	Flow	Constraint	Process
Primary effect	Uniform process output	Increased customer satisfaction	Reduced flow time	Fast throughput	Increased process capability
Secondary effects	Better financial performance, reduced waste, fast throughput, reduced inventory	Customer loyalty, increased performance	Reduced variation, reduced inventory, improved quality	Reduced inventory, reduced waste, improved quality	Increased customer satisfaction, improved quality
Criticism	System interaction not considered, no customer satisfaction	No tangible improvements, resource-demanding, unclear notion	Reduces flexibility, statistical analysis not values	Minimal worker input, data analysis not valued	No improvement, ad-hoc solutions

3.7 Design for Six Sigma (DFSS)

Sokovic and Pavletic (2007) define DFSS as a systematic and structure approach to new products or processes design that focuses on “problem prevention”. Similar to six sigma strategy, output requirements about customer CTQs are tried to be targeted or exceeded. The major objective of DFSS is to “design things right the first time”.

DFSS uses a different methodological cycle called DMADV, the acronym for Define – Measure – Analyze – Design – Verify.

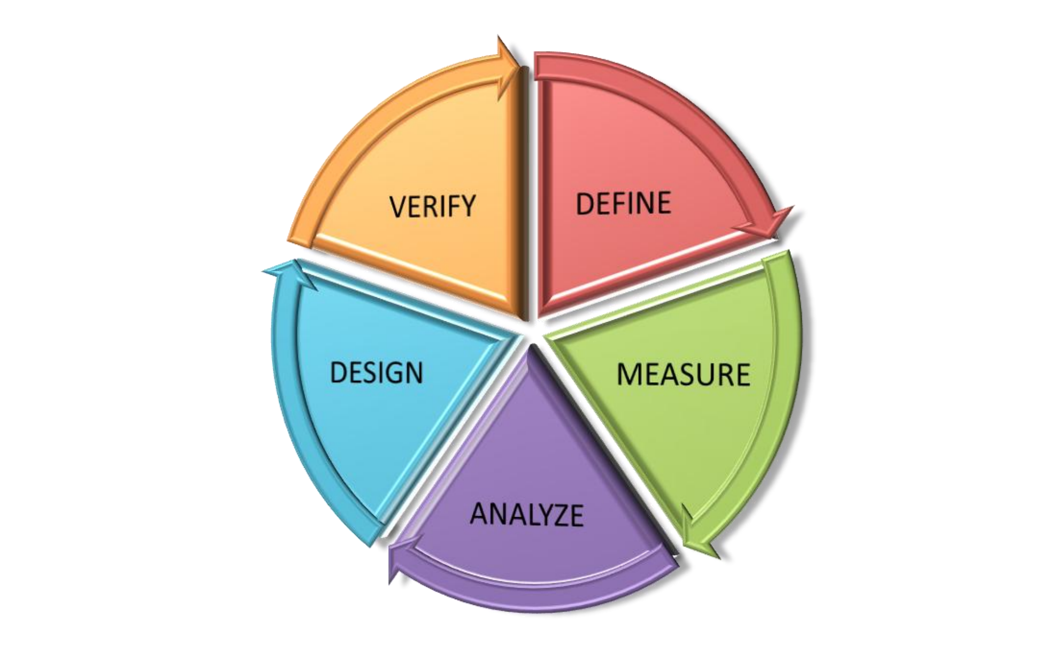


Figure 3.6 DMADV cycle

"The essence of DFSS is predicting design quality up front and driving quality measurement and predictability improvement during the early design phases –a much more effective and less expensive way to get to six sigma quality than trying to fix problems further down the road" (Treichler, Carmichael, Kusmanoff, Lewis, & Berthiez, 2002).

Since detailed discussion of DFSS is beyond the scope of this work, no further details are given. However, in Section 4.19, the situation of DFSS in academic literature is reviewed.

3.8 Companies Implementing Six Sigma

A short list of companies using six sigma in different regions is given in the following figure (Andersson et al., 2006; Harrold, 1999; McCoy, 1999; Pande et al., 2004; and van den Heuvel, Does, & Vermaat, 2004). As the figure shows, six sigma practitioners are often world-class firms who have a reputation for good quality.

The US and Canada

- Motorola
- GE
- American Express
- Boeing
- Citibank
- Dow
- Ford
- AlliedSignal
- DuPont
- Black&Decker
- Bombardier
- Federal Express (FedEx)
- Johnson&Johnson
- Kodak
- Navistar
- Polaroid
- Seagate Technologies

Europe

- Daf Trucks
- Nokia
- Phillips
- Asea Brown Boveri
- Siebe Appliance Controls
- Ericsson
- Volvo

Japan

- Sony
- Toshiba

Figure 3.7 Some companies implementing six sigma

CHAPTER FOUR
LITERATURE ON SIX SIGMA

Vast of written materials can be found on a popular subject like six sigma. To study the literature, the analyst has to find reliable sources with academic character and eliminate others.

Science Citation Index (SCI) is defined by its owner Thomson Scientific as an index of "current and retrospective bibliographic information, author, abstracts, and cited references found in 3,700 of the world's leading scholarly science and technical journals covering more than 100 disciplines".

Journals listed in Science Citation Index Expanded are searched for words *six sigma* or *6 sigma* within titles or subjects. Results were filtered in order to eliminate other publication types –such as book chapters, etc.- and unrelated articles –such as articles about astronomy or physics including the words in a completely different context. Remaining set includes 245 articles. List of the journals including at least one article about six sigma is given in Appendix I. For reasons like unavailability of the electronic copy of some articles, 208 of the articles could be reached and analyzed in full text. Since there is no clue of a pattern in the properties of available/unavailable articles, and the sample coverage is 85 percent, which is relatively high, the study is believed to represent the SCI-Expanded literature on six sigma. Analysis that can be conducted by using the bibliographic information like date and author affiliation are done in a set of 245 articles. On the other hand, analysis that necessitate full-text availability of the article are conducted within 208 full-text articles.

The following properties of the literature will be studied in the framework of the analysis made:

1. Date of the article
2. Geographical location of the corresponding author

3. Affiliation (academy vs. industry) of the corresponding author
4. Keywords
5. Subject of the publication
6. Number of citations
7. Having “six sigma” as the main subject of the study
8. Case study inclusion
9. Related sector/field
10. Definition of six sigma
11. DMAIC
12. Other quality initiatives
13. Success factors
14. Criticism about six sigma
15. The future of six sigma
16. Challenges in six sigma implementation
17. Performance measurement
18. Tools
19. Design for Six Sigma (DFSS)

For the statistical analysis conducted in this chapter, Microsoft Excel 2007 is used. Appendix II provides a list of the articles analyzed and a summarized table including the raw data on the 19 subjects of review.

Brady and Allen (2006) made a literature review on six sigma. The authors tried to describe trends, sources, and findings in a set of 201 articles derived by a SCI Expanded search, but with different descriptors that the ones used in this study. The topics discussed in the study include a topic classification, which is avoided in this review because of the high subjectivity of this analysis implied by the high transitivity. In other words, to determine if an article in the set includes a discussion of practices or tools or philosophy or techniques or etc. is difficult because of the transitivity. Moreover, in the aforementioned review, journal impact factors were a part of the analysis. Journal impact factors (supplied by SCI) provide a rough measure of journal quality or impact based on their citation statistics. They are not included in this study because it is believed that, in industrial engineering field, the importance of articles/journals might not represent their value correctly.

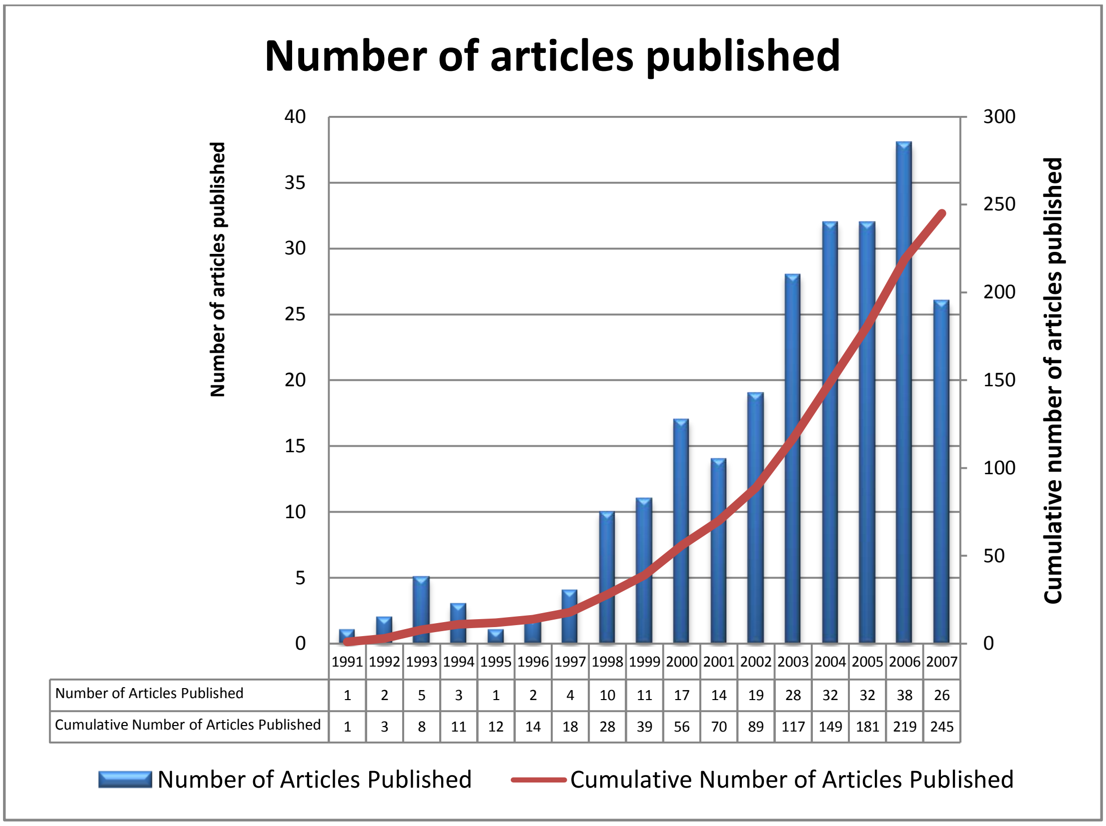
The common subjects of analysis among Brady and Allen’s (2006) literature review and this study include author affiliations, sectoral distribution, success factors and performance measurement. The current review on the articles that contain phrase *six sigma* in title or subject parts, complements and enhances Brady and Allen’s review. Partial agreement in trends and findings about common topics analyzed can be found. Their findings will be referred to within the chapter if necessary. Besides these, this review includes discussion of topics not discussed by Brady and Allen, such as definition, criticism, ideas about the future of six sigma, challenges, tools, and so on.

4.1 Date of the Article

In the review, no time limits are set. However, as it is described in the chapter about the history of quality, six sigma is a relatively new concept, emergence of which dates back to the mid 1980s.

The first scholarly article indexed by SCI Expanded bears the date 1991. Since that year, the academic literature about six sigma grew at a fast pace. The last article indexed is one of year 2007, in which this analysis was conducted.

Figure 4.1 shows the number of articles published in each year. The red line indicates the cumulative number of articles published up to the relevant year.



	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Number of Articles Published	1	2	5	3	1	2	4	10	11	17	14	19	28	32	32	38	26
Cumulative Number of Articles Published	1	3	8	11	12	14	18	28	39	56	70	89	117	149	181	219	245

Figure 4.1 Number of articles published

An increasing trend is apparent in the figure. Starting year 1991 indicates that the industrial practices initiated in 1986 triggered academic interest after 5 years of success. Even after that, the number of publication remained below 5 until 1997; but afterwards the increasing character became obvious. Ignoring a small decrease in 2001, the number of articles published each year steadily increased until 2006.

It must be noted that after 1995, when General Electric's six sigma program gained success and public attention, studies on six sigma gained further impetus. The sharp decrease in year 2007 is not analyzable because this study is conducted in that year and trends could not be derived before 2007's last issues of all the journals spanned by SCI Expanded are published and indexed.

Brady and Allen (2006), in their six sigma review, argue that the condemnations in popular press such as Clifford (2001) in Fortune Magazine are the reason of the slight decrease in 2001. Clifford (2001) in his article "Why You Can Safely Ignore

Six Sigma?”, had claimed that “six sigma, and a couple of similar-looking knockoffs, are nothing short of a full-on corporate fad, the latest in a long line of must-have efficiency crazes that perpetually spread through corporate America.”. As the proponents of six sigma sprang up, opponents escalated concurrently. This might had a negative effect in the early 2000s, but the continuing success of the practices forced the trend upwards.

4.2 Geographical Location of the Corresponding Author

Discussion in the chapter about the history claimed that six sigma is in fact an American response to Japanese success in quality. This claim is investigated in the academic literature. 145 of the 245 articles analyzed within this study are written more than one author, therefore the location of the corresponding authors are taken into consideration. Contact addresses of the corresponding authors are supplied by SCI Expanded for each article, with an exception of 43 articles in this study. These addresses were grouped by their countries. The results of this analysis is shown in a Pareto chart in Figure 4.2.

The figure confirms that the US is the primary source of six sigma studies. This information is in agreement with the historical origins of six sigma. European studies sum up to 44, which is less than half of the number of the US-origin ones. Japan, whose quality tradition and success was confronted with six sigma, contributes with a single article.

A visualization of this information on a world map is given in Figure 4.3.

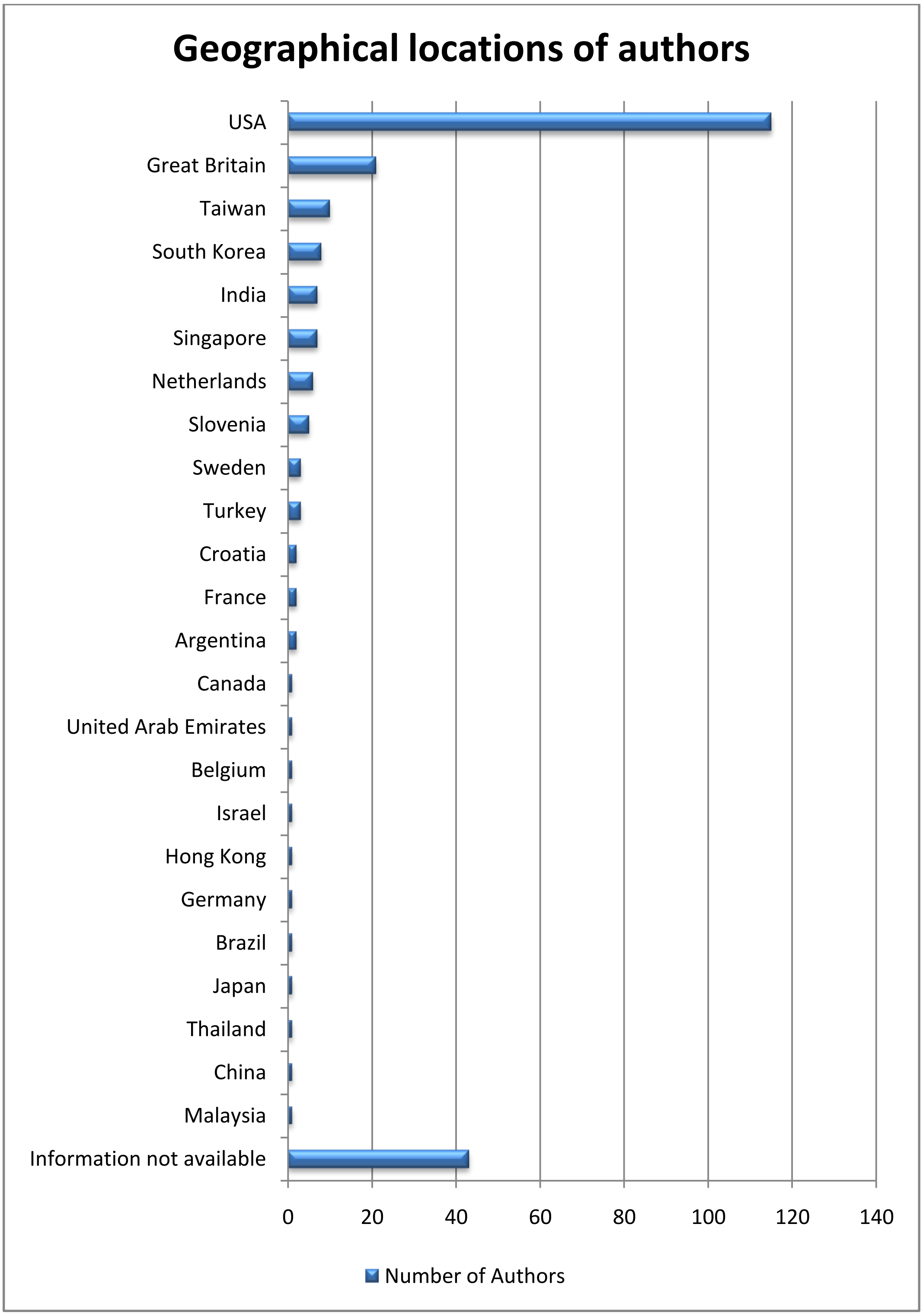


Figure 4.2 Geographical locations of corresponding authors

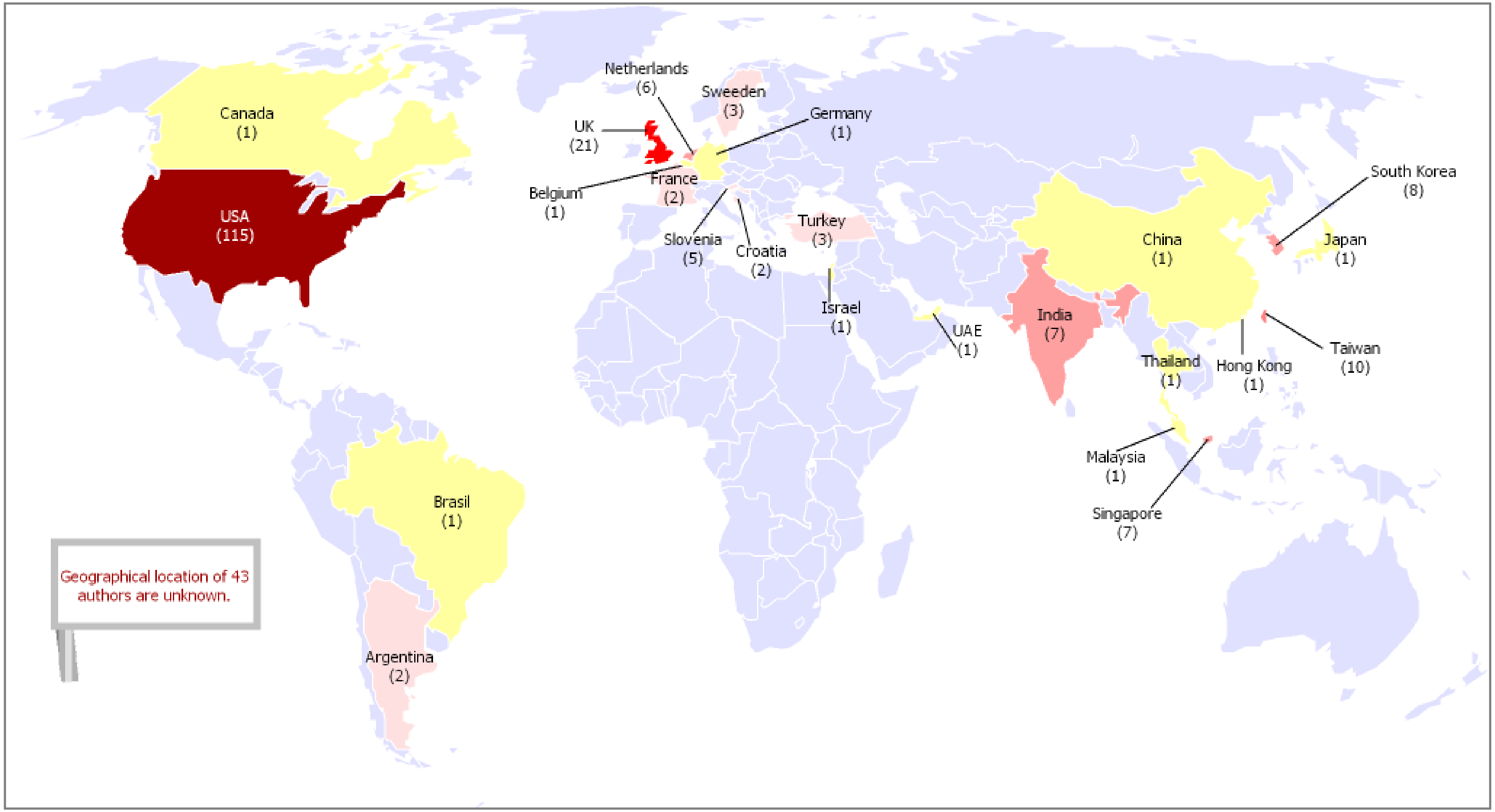


Figure 4.3 Geographical locations of corresponding authors shown on a world map

4.3 Affiliation of the Corresponding Author

In this section, traces of the industry origins of six sigma is explored in the academic literature. Some articles are written by authors from academy (who are affiliated with a university, college, etc.); and some by authors from industry who has no academic hat but enough practical information to produce an scholarly article. There are 145 multi-author articles. Some of them are created by authors from both sides. In the analysis, the affiliations of the corresponding authors are considered. Lastly, SCI Expanded does not provide any information about the affiliations of the 43 corresponding authors, so they are handled separately. Figure 4.4 shows the percentages of the author affiliations

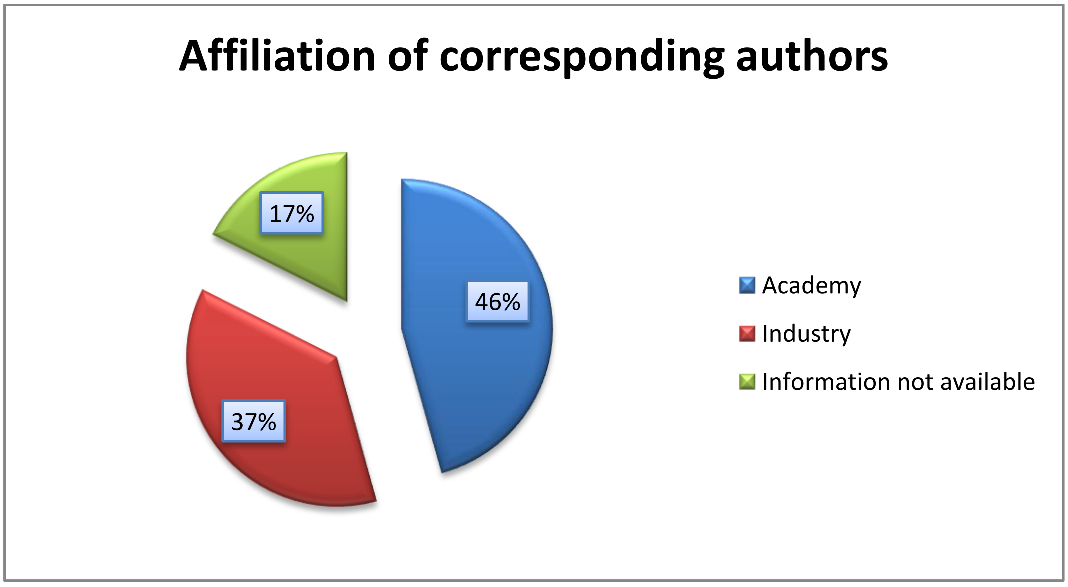


Figure 4.4 Affiliations of corresponding authors

Although academicians constitute the majority of the authors, it must be noted that the review is made among academic journals whose academic character is authenticated by SCI Expanded. Given this condition, the high percentage of practitioners from industry shows us that six sigma is a popular subject in industrial world, maybe more than it is in academia. Besides this, joint articles with correspondence to academicians are not uncommon in the list. Therefore, second or third authors having industry affiliation are disregarded if the corresponding author is affiliated with academy. Even besides that, the authors with unavailable information are believed to be affiliated more with the industry, since titles of professors are rarely ignored by the journals. To see the change of these percentages within years, the following figure is given.

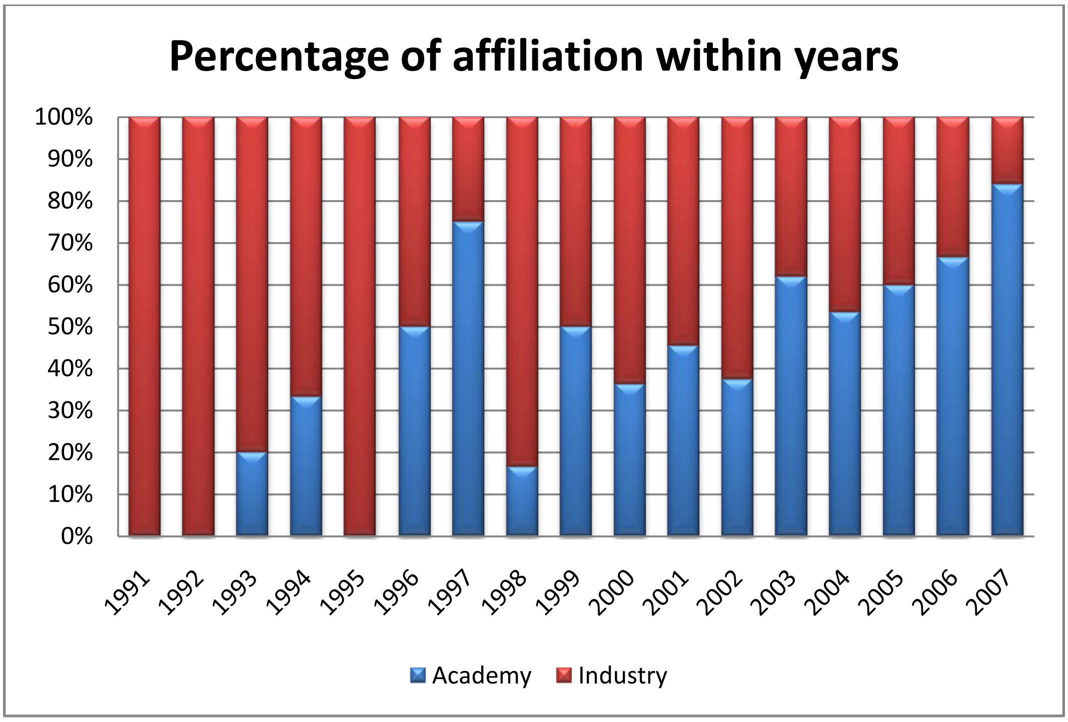


Figure 4.5 Percentage of affiliations of the corresponding authors within years

This figure shows that the interest among academicians is growing. Brady and Allen (2006) discover a similar trend, and find this “not surprising considering the industrial origins of six sigma”.

All these considerations lead us to the following hypothesis: Six sigma, which is an overwhelming craze in the industry and a money-raiser for practitioners, is starting to gain a fairly new interest in academia.

4.4 Keywords

Of the 245 articles, 128 include 391 different author-defined keywords. Similar keywords with typographic differences are eliminated and grouped with a common name. The keywords used 5 times or more are listed in Table 4.1.

Table 4.1 List of author-defined keywords used at least 5 times

Keyword	Times used
Six sigma	67
Quality	17
Design of experiments	10
DMAIC	10
Process improvement	9
Six Sigma methodology	6
Design for six sigma	6
Quality improvement	6
Reliability	5
Robust design	5
Case study	5
Lean	5
Statistical process control	5

The pareto rule (80%-20%) is applicable for the keywords of the articles, which indeed can give limited information about the character of the literature. 52 percent of the articles have “six sigma” as a keyword. This high percentage may be an evidence of two things: Either the relevance of the articles reviewed in this study to six sigma is very high (this question is addressed in Section 4.7), or writing *six sigma* in the keyword field may be desirable for authors who want their articles to be listed in six sigma search results. It is believed that both are correct to some extent.

General terms such as “quality” and “process improvement” are used as keywords frequently. Other popular keywords represent statistical tools studied/used in the articles. *DFSS* is included in the keyword lists of only 6 articles, which is surprising when the increasing interest on the methodology is considered.

4.5 Subject of the Publication

A subject categorization of journals is given by the SCI Expanded. One journal may have more than one subject category. Under this circumstance, the journal subjects with occurrences of 10 times or more are listed in Table 4.2.

Table 4.2 Subject categories of articles with occurrences of 10 times or more

Subject of the Publication	Number of articles
Operations Research & Management Science	69
Engineering, Multidisciplinary	57
Engineering, Industrial	47
Management	36
Engineering, Manufacturing	29
Engineering, Chemical	19
Engineering, Electrical & Electronic	18
Engineering, Mechanical	16
Automation & Control Systems	15
Engineering, Aerospace	13
Statistics & Probability	10

High numbers of OR/MS and industrial engineering journal articles are in accordance with the nature of the subject. Articles published in management journals are not uncommon. This is expected because of the managerial aspect of six sigma, which is an important part of the methodology.

Brady and Allen (2006) believes that applied statistic journals dominate the six sigma literature and underlines the irony of this fact with high number of practitioners with little or no formal training in statistics. However, SCI does not categorize the journals mentioned by Brady and Allen[10] as “applied statistics” journals but as multidisciplinary engineering journals, OR/MS journals and industrial engineering journals; three categories which dominate the table. Still, when the

[10] Brady and Allen (2006) used a different set of search descriptors, therefore their sample is somewhat different. The common dominant journals are “Quality Progress” and “Quality and Reliability Engineering International”.

commonality of statistics discussion in the articles is considered, there is no reason to disagree with Brady and Allen.

A fact not represented in this analysis is the high number of articles published in medical journals. The reason why this information is not represented is the diversity of the subjects of medical journals[11]. A total of 38 articles were published in journals related to medicine, which would put the item to the fourth place in ranking if the journals could be pooled in one title.

4.6 Number of Citations Received

SCI Expanded provides citation statistics for every article published in an indexed journal. A total of 592 citations were made to the 245 articles about six sigma. 108 articles were never referred to. 13 articles of 245 were cited more than 10 times, which makes 5%. This number is much smaller than the general average estimation. Garfield (1976) estimates that less than 25% of the articles published ever is cited 10 times in all eternity (Garfield, 1976). The articles which received more than 20 citations are listed in Table 4.3.

Table 4.3 Articles received more than 20 citations

Authors	Year	Title	Journal Name	Times Cited
Chassin, MR	1998	Is health care ready for six sigma quality?	Milbank Quarterly	105
Du, XP; Chen, W	2000	Towards a better understanding of modeling feasibility robustness in engineering design	Journal of Mechanical Design	32
Feng, CXJ; Kusiak, A	1997	Robust tolerance design with the integer programming approach	Journal of Manufacturing Science and Engineering - Transactions of the ASME	24
Nevalainen, D; Berte, L; Kraft, C; Leigh, E; Picaso, L; Morgan, T	2000	Evaluating laboratory performance on quality indicators with the six sigma scale	Archives of Pathology & Laboratory Medicine	22

[11] 17 different medical journal subjects are noted, some of which are “Medicine, General & Internal”, “Surgery”, “Hematology”, “Radiology, Nuclear Medicine & Medical Imaging”, etc.

The articles with higher citations appear not to be mainly about six sigma. For instance, Du and Chen's (2000); and Feng and Kusiak's (1997) are within the pool of full text articles and marked as "not mainly about six sigma". The article may be about a single tool used in six sigma methodology or a completely different subject which included "six sigma" in an introduction sentence coincidentally. It is not surprising that articles with narrower scopes are cited frequently by researchers. However, the low citation performance of the six sigma articles raises questions about the academic character of six sigma articles.

Another analysis about citations can be made from a different perspective. Number of references to other articles is another set of data provided by SCI Expanded. This analysis shows that 66 of the articles do not refer to any other material at all, supporting the suspicion about the academic character.

4.7 Relevance to Six Sigma

Relevance to "six sigma" differs among the articles. While some articles were mainly about six sigma implementations/case studies, some of them were about a single tool which may or may not be used in six sigma methodology. Some articles, even though they cannot be described to be "mainly about six sigma", are included within our list because they have "six sigma" in their subject/abstract parts. The relevance of full-text articles to the subject and the change in this statistics within years are given in the Figures 4.6 and 4.7.

Figure 4.6 indicates that 3 in 10 articles having "six sigma" in title or subject parts are assessed to be (this analysis surely comprises subjectivity) not mainly about the subject. The articles that use the string *six sigma* in their title or subject parts increase in time. This might be attributed to the increasing attention to the subject. Six sigma is proved to be a good advertisement tool in the industry and the advertising effect seems to be used in academic literature too. It is an interesting note that 13 of the 63 articles that are not mainly about six sigma has "six sigma" in the author-defined keywords list.

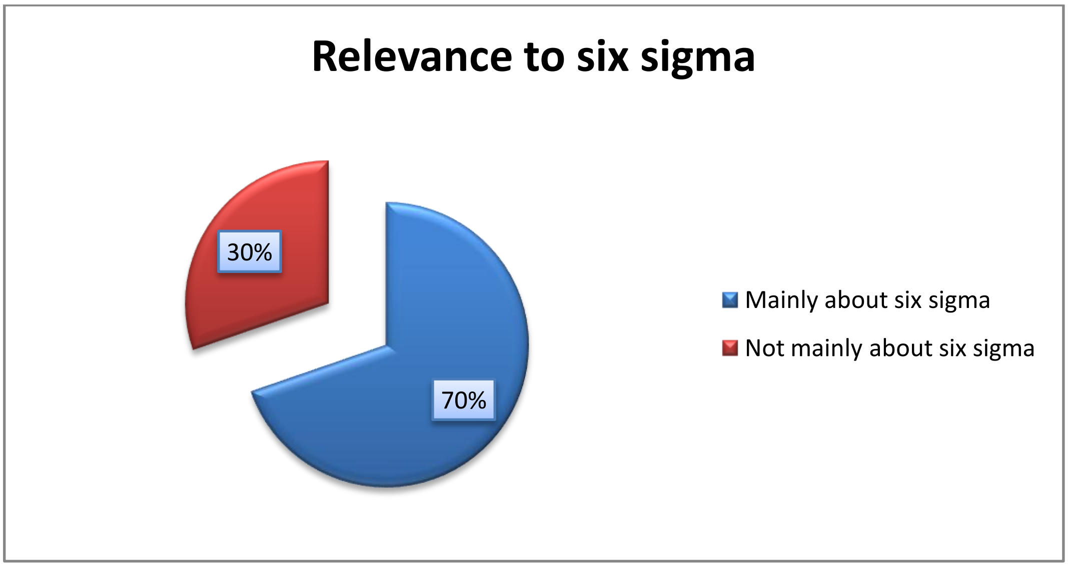


Figure 4.6 Percentage of relevance of articles to six sigma

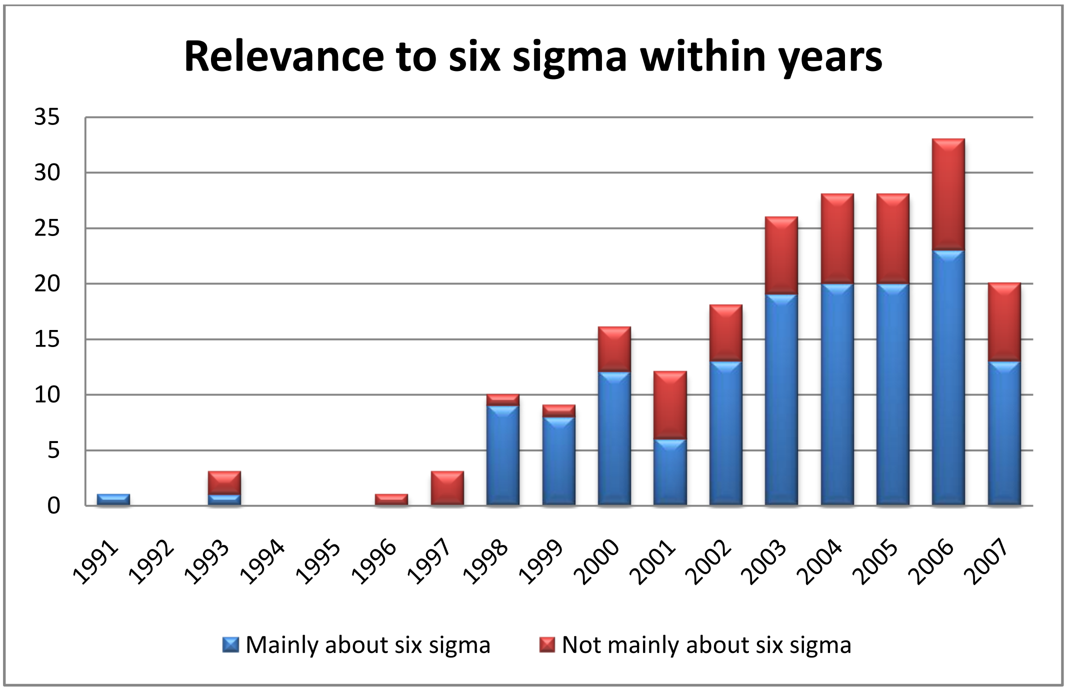


Figure 4.7 Relevance of articles to six sigma within years

Figure 4.8 shows the distribution of affiliation of authors whose articles are not mainly about six sigma.

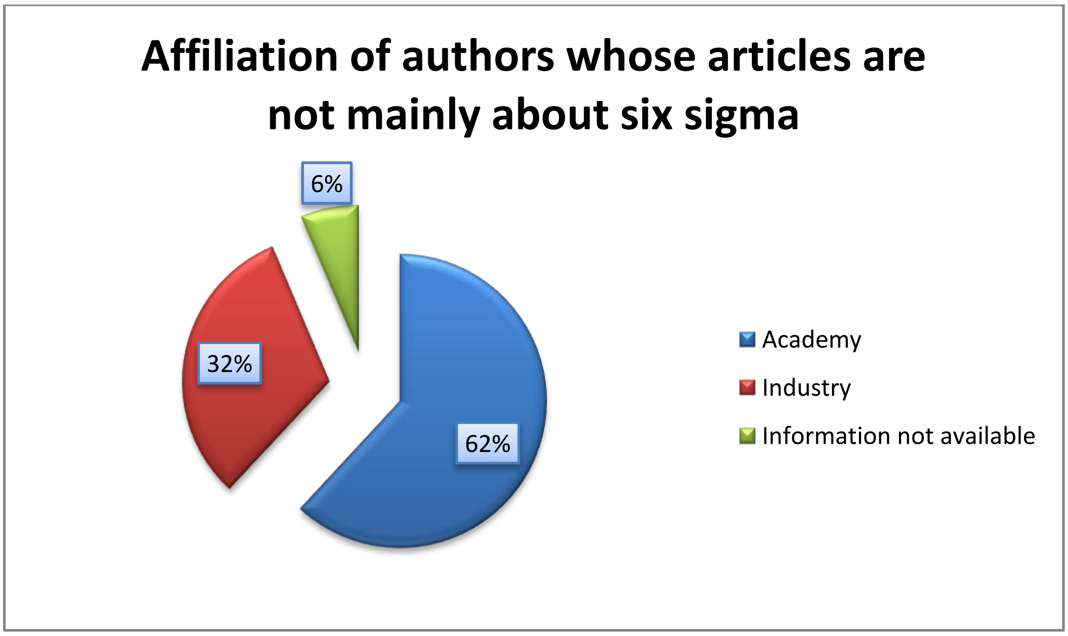


Figure 4.8 Affiliation of authors whose articles are not mainly about six sigma

As the figure indicates, most of the articles not mainly about six sigma are the ones of academicians. During the study, it is observed that academicians generally target narrow subjects which require expert knowledge. Articles about control limits of SPC charts can be an example of this. As the subject of the article gets narrower, the chances that it will be classified as “not mainly about six sigma” increases, as it is the case in the example mentioned. This might be the main reason for the high percentage of academicians in Figure 4.8.

4.8 Case Study Inclusion

120 of the 208 articles include at least an implementation example, i.e. case study; whereas 88 of the articles include no mention of an implementation. Of the 120 articles with case studies, 26 articles include a conceptual discussion too. The percentages of these types are represented in the following figure.

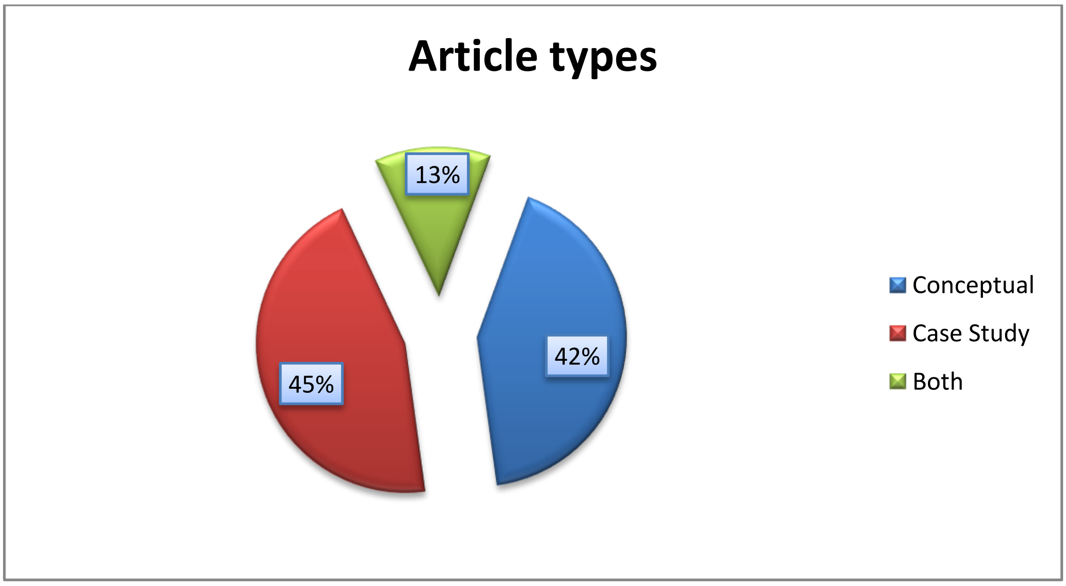


Figure 4.9 Article types

The analysis shows that more than half of the literature includes case studies. This is in accordance with the hypothesis that six sigma concept is built upon practice and backed up with a strong statistical theory. Same argument applies to the articles mainly about six sigma, as shown in Figure 4.10.

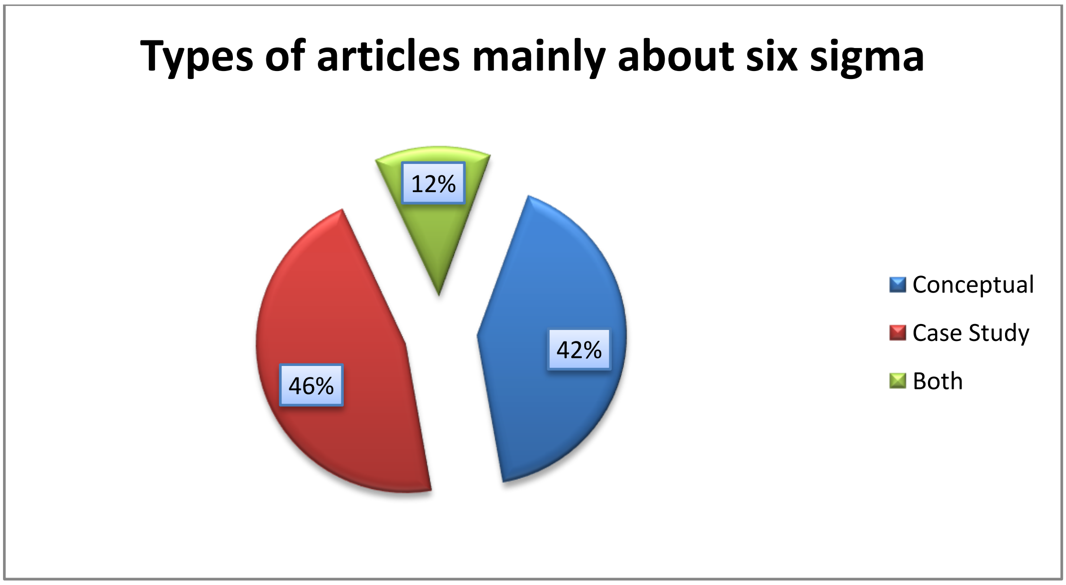


Figure 4.10 Types of articles mainly about six sigma

Figure 4.11 shows the change trends in this distribution within years.

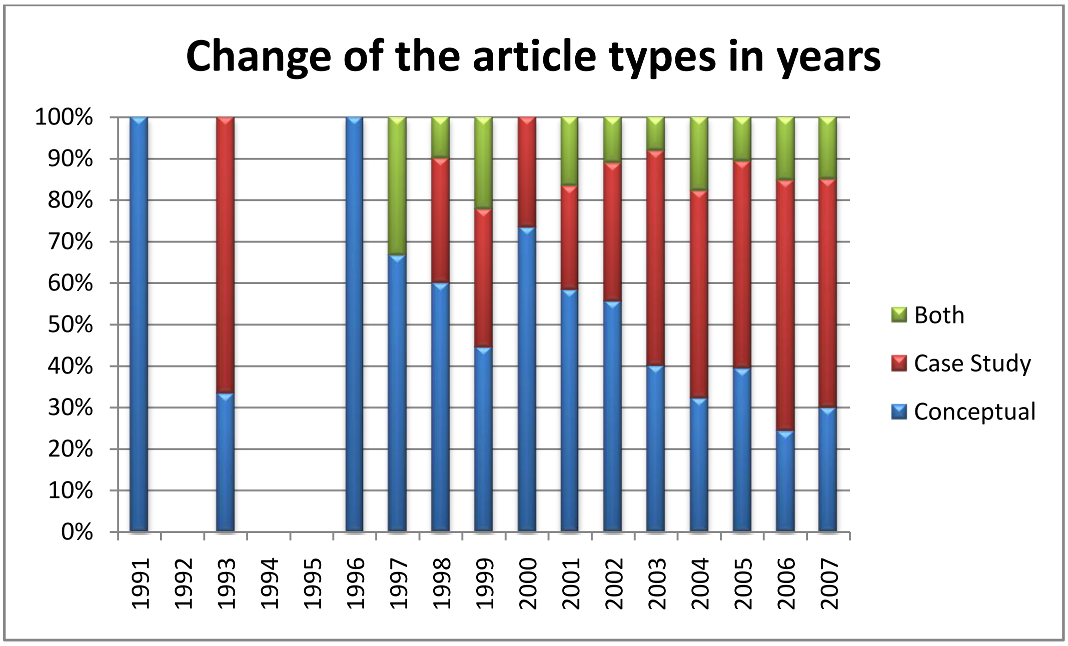


Figure 4.11 Change of article types within years

As the figure indicates, conceptual articles are in a declining trend where case studies become more popular. This trend is more visible after year 2000.

4.9 Related Sector/Field

160 of the 208 full-text articles were related with a specific sector. These articles either mentioned case studies in a sector, or included discussion with mentioning the sector their subject is applicable to.

In the analysis, 12 different sectors are identified and the data about them are shown in a Pareto chart in Figure 4.12. The figure shows clearly that the manufacturing-origin of six sigma is maintaining its dominance. Second most frequently studied sector is healthcare, which is very suitable for six sigma studies for its error-intolerant nature.

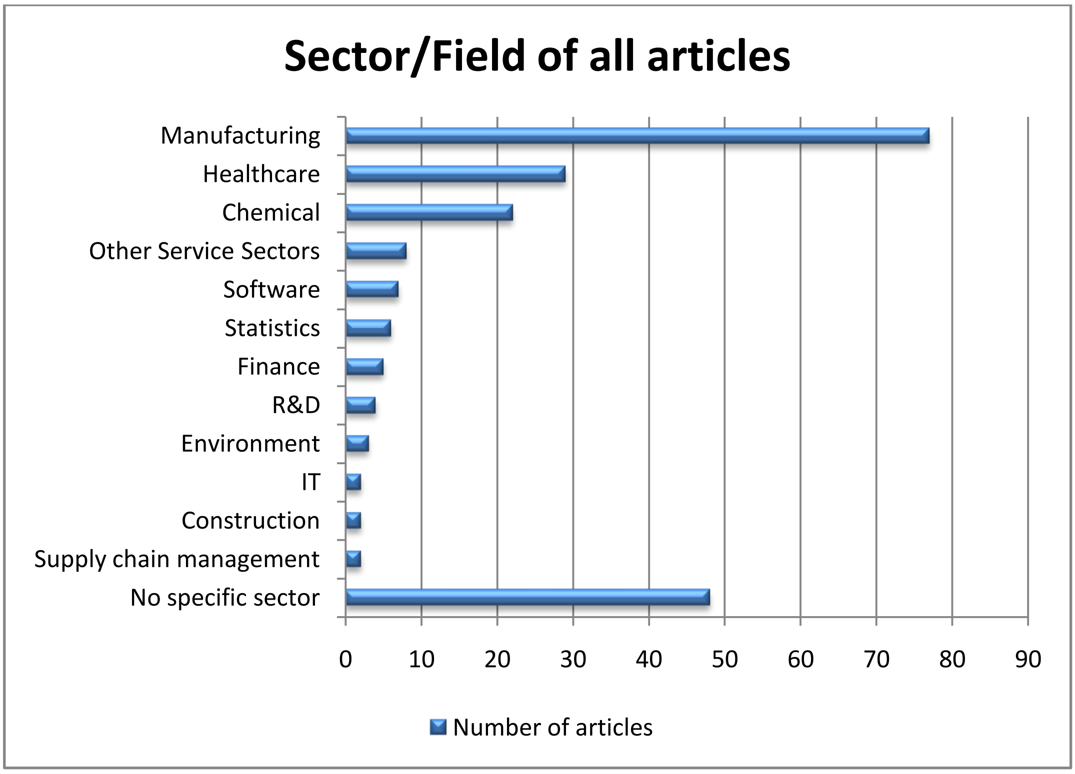


Figure 4.12 Sector/field of all articles

If we group manufacturing, construction, chemical, and R&D sectors under "Manufacturing" title; healthcare, finance, software, environment, IT, and other service sectors under "Service" title; and eliminate other fields; the resulting distribution is given in Figure 4.13.

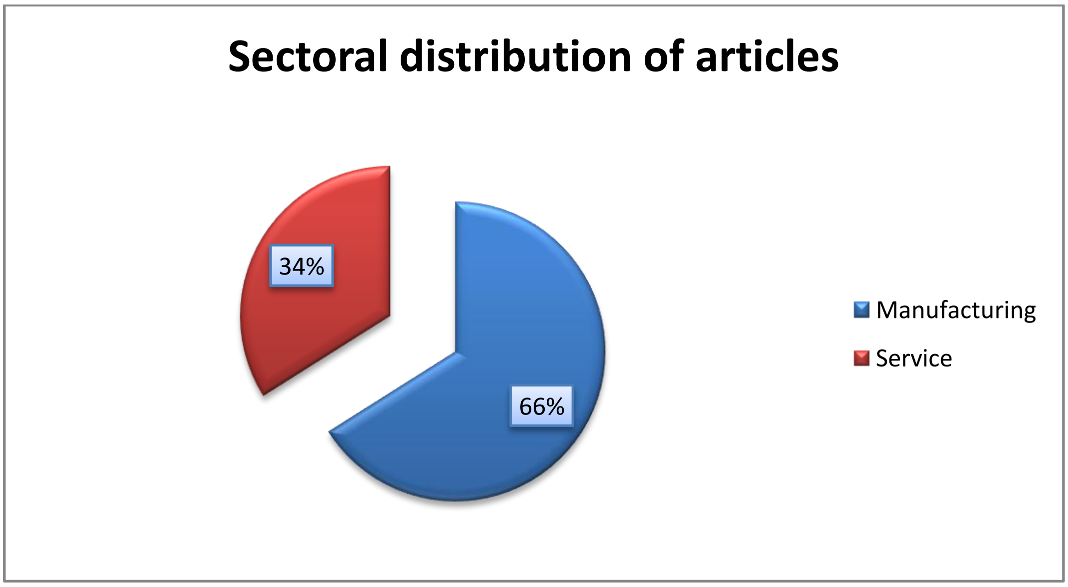


Figure 4.13 Sectoral distribution of articles

This figure gives the same result that manufacturing dominance in the literature is valid. However, rather than deriving the sectors/fields of all 208 full-text articles, the analysis of the ones that are mainly about six sigma could give better insight about this. The articles that are not mainly about six sigma may be related to a specific sector, for illustration healthcare, but for a six sigma literature review, trends in six sigma literature should be discussed based on articles mainly about six sigma. Following figures show the analysis results.

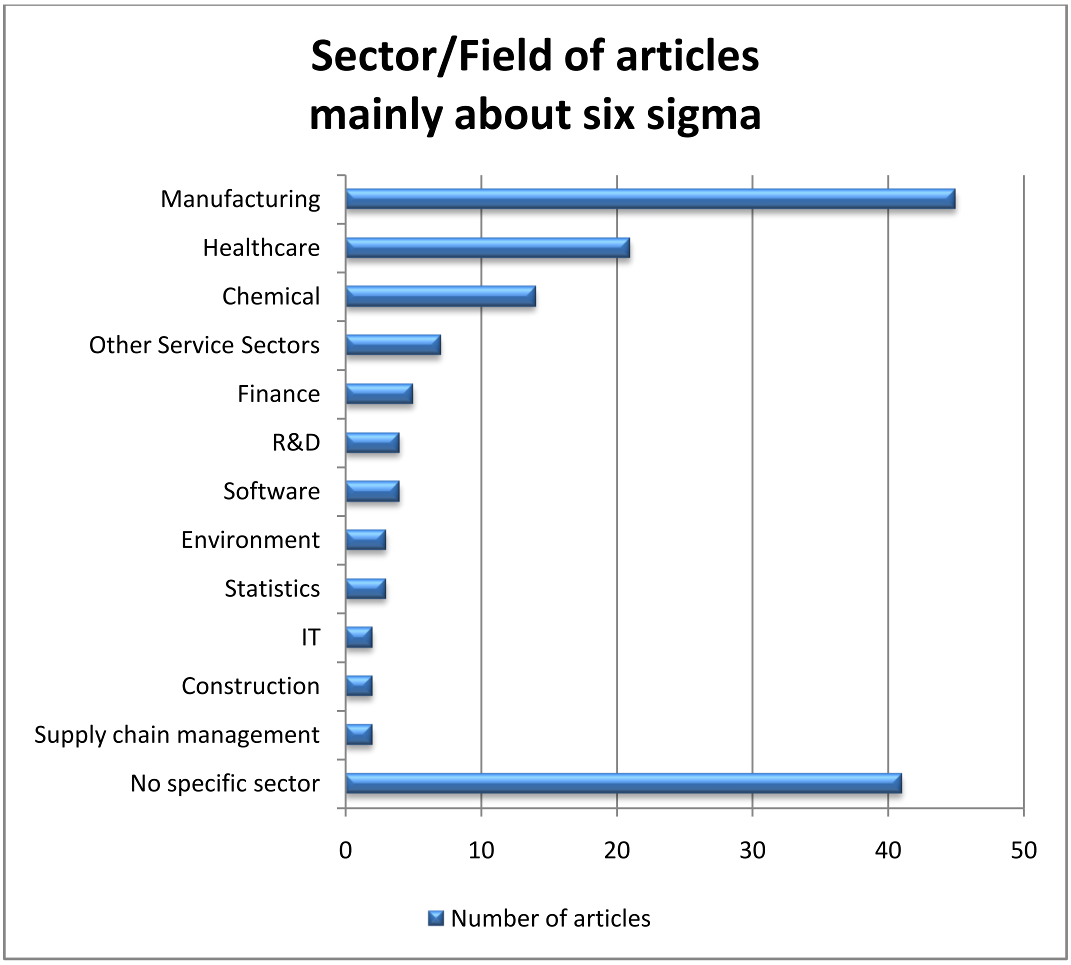


Figure 4.14 Sector/field of articles mainly about six sigma

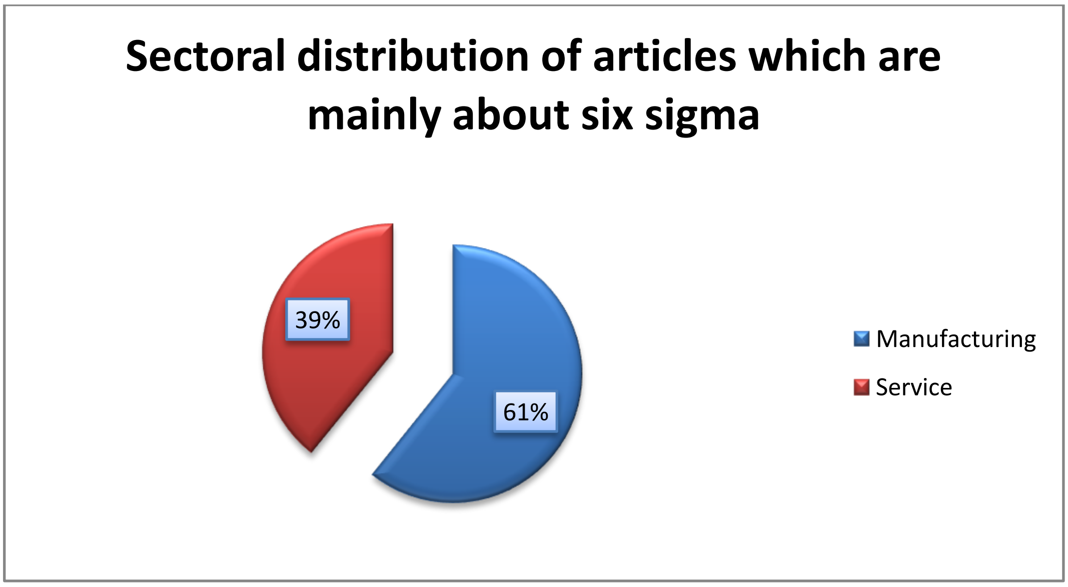


Figure 4.15 Percentage of sectoral distribution of articles mainly about six sigma (manufacturing – service)

The distribution do not change significantly when the articles which are mainly about six sigma are handled. In the articles which are mainly about six sigma, the percentage of service oriented articles increases by 5%, from 34% to 39%.

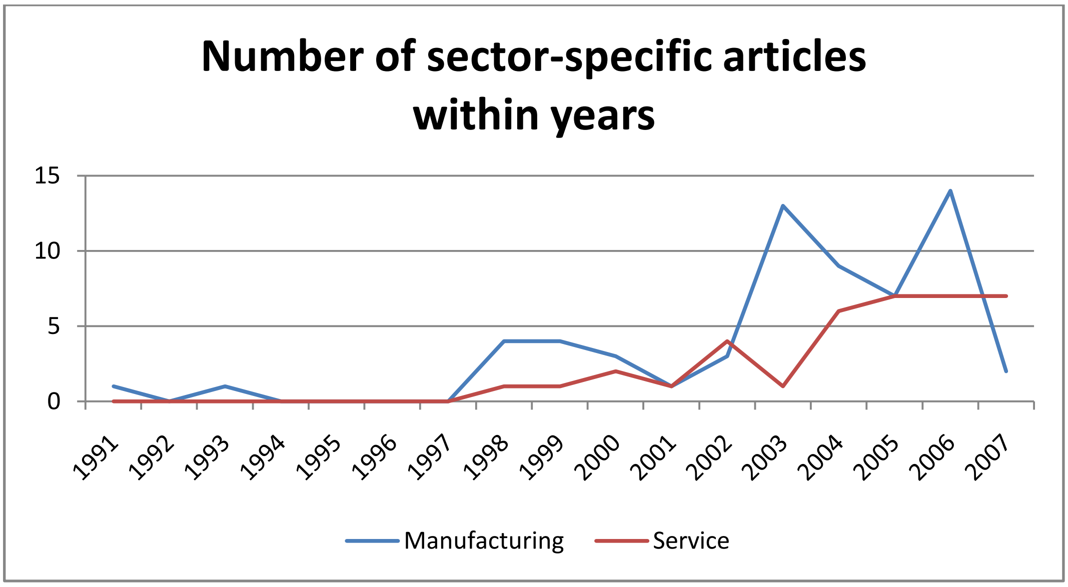


Figure 4.16 Number of sector-specific articles within years

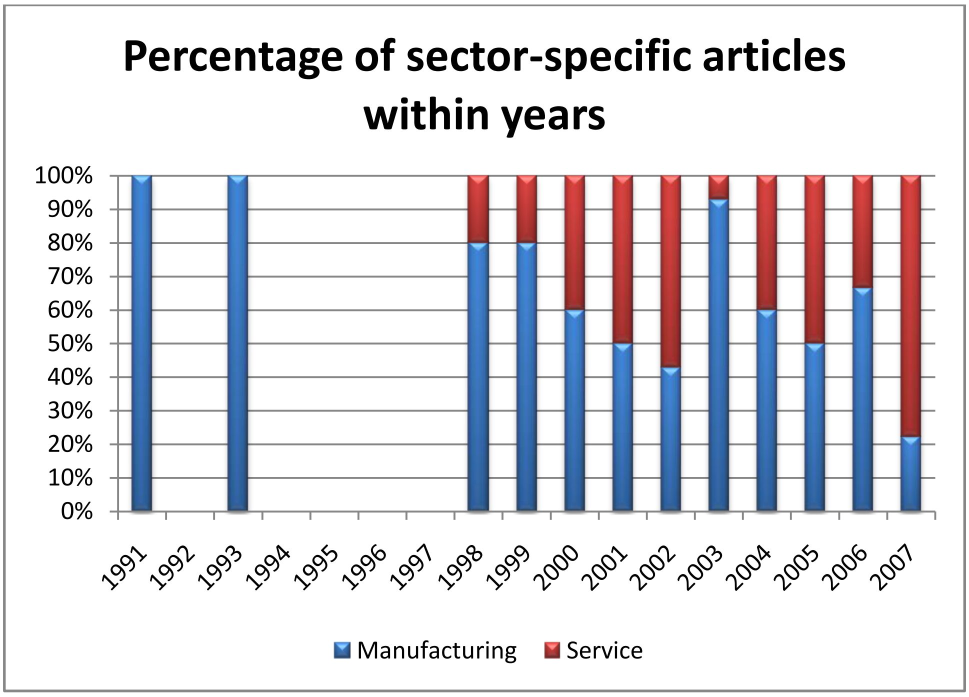


Figure 4.17 Percentage of sector-specific articles within years

Figures show the trends in sectoral interests in six sigma literature. In the first graph, while the manufacturing oriented articles show no clear pattern in the graphic, number of service oriented articles seems to be increasing with time. The increasing pattern in service-oriented articles is verified in the second graph, which shows the relative amount of manufacturing-oriented articles are diminishing although it is not a steady decrease. This is an expected pattern, because the number of implementations in service firms or non-manufacturing functions of manufacturing firms increased when the industry remarked the success of the methodology –in manufacturing environments. Hoerl (1998) foresees that “while quality jobs may decrease in manufacturing over the next decade or so, a large number will be created in finance and other nonmanufacturing businesses”. Quality studies in service sector are a promising area of study.

Figure 4.18 shows the affiliations of the authors with respect to sectors studied.

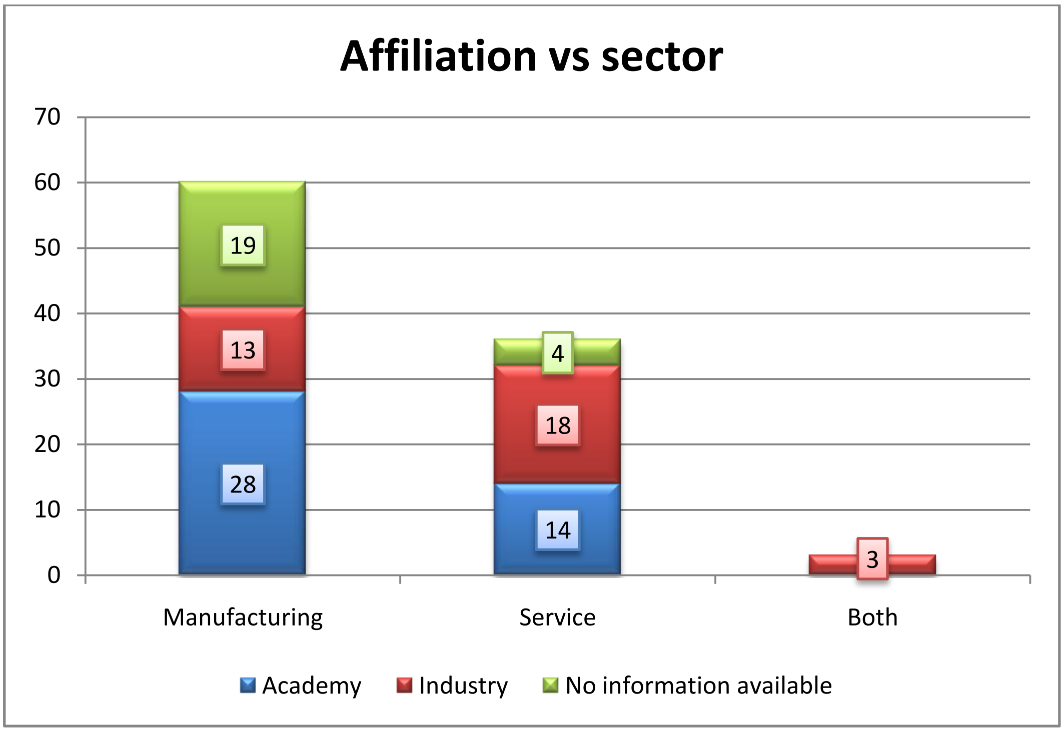


Figure 4.18 Affiliations of corresponding authors versus sectors studied

According to the figure, academicians tend to study manufacturing sector more (47%) rather than service sector (39%). This shows the tendency of academicians to study traditional manufacturing environments. However, as shown in Figure 4.19, this tendency is also changing.

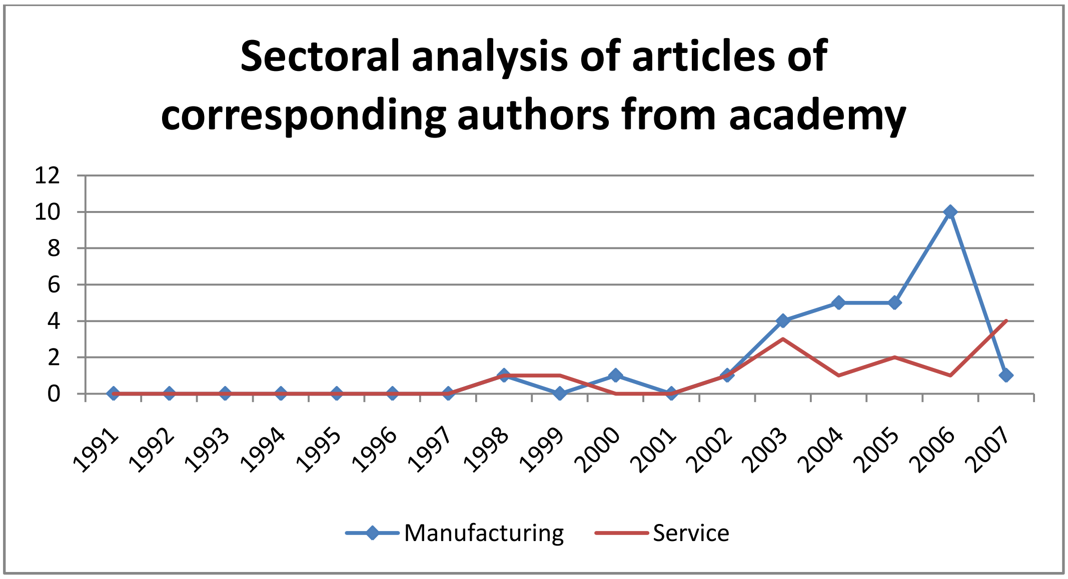


Figure 4.19 Sectoral analysis of articles with academic corresponding authors

Service sector studies in academic world are increasing in number while no certain pattern can be put about manufacturing sector, because of the significant decline in 2007. Since this review was made in 2007, it is difficult to find the reason of this decrease. To identify if this is a new decrease trend or not, the analysis should be repeated in the following years.

Figure 4.20 shows the trends in number of studies with authors from industry.

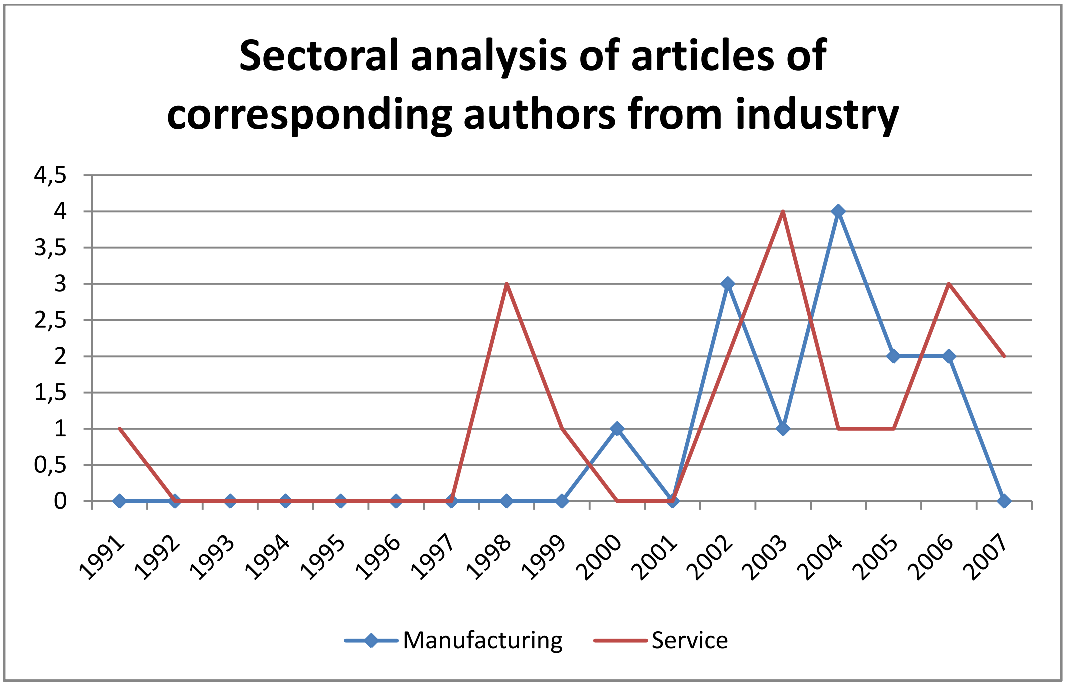


Figure 4.20 Sectoral analysis of articles with authors from industry

This graph reveals the lowering interest in manufacturing sector after year 2004. Practitioner authors in manufacturing sector are contributing with fewer articles with academic character.

If solely articles including case studies are taken into account, a different sectoral distribution is found. This is represented in Figure 4.21.

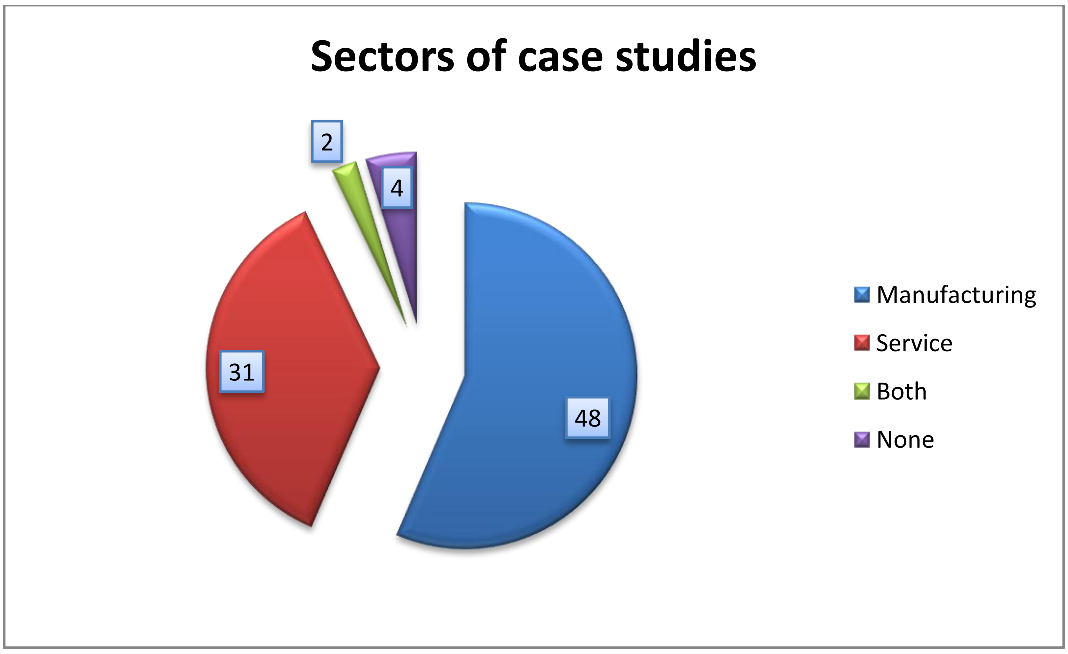


Figure 4.21 Sectors of case studies

Case studies in service sector are more frequent when compared to conceptual articles. Articles in healthcare, with 15 out of 31, constitute the majority of this group. Category named “None” refers to articles with case studies (problems) not mentioning any specific sector but could be applicable to many sectors.

4.10 Definition of Six Sigma

Putting an all-round definition for six sigma concept is challenging. No single definition is present for the concept, but every author puts his or her own perspective of six sigma forward. Linderman et al. (2003) say that “six sigma concept has not been carefully defined in either the practitioner or academic literature”. There is no consensus among authors about whether six sigma is a tool, toolset, method, methodology, philosophy, management system, quality improvement system, or process improvement strategy etc.

In this section, rather than proposing a full definition including elements from tools, methods, culture, and success factors like Brady and Allen (2006) did, giving an insight to the approaches of articles in six sigma literature is aimed.

Kwak and Anbari (2006) highlight two perspectives about the definition of six sigma: Statistical viewpoint and business viewpoint.

- Statistical viewpoint: This viewpoint gives definitions emphasizing the statistical, probabilistic and quantitative aspects of six sigma. Generally preferred terms in the definition include “3.4 DPMO”, “variation”, “tool”, and “methodology”.

- Business viewpoint: This viewpoint gives definitions emphasizing the improvements in business profitability, effectiveness and meeting customer requirements. Generally preferred terms in the definition include “customer”, “business”, and other management concepts.

Pheng and Hui (2004) exemplify five different descriptions from various articles and classifies them into two groups:

- “Six sigma is a statistical measure used to measure the performance of processes or products against customer requirements. This is known as the technical definition of six sigma.

- Six sigma is a “cultural and belief” system and a “management philosophy” that guides the organization in repositioning itself towards world-class business performance by increasing customer satisfaction considerably and enhancing bottom lines based on factual decision making.”

Resemblance of the classifications in both articles is evident: One perspective with a technical/statistical emphasis, and another perspective with a business/management emphasis. Figure 4.22 displays the types of definitions provided in the 145 articles mainly about six sigma and based on this classification.

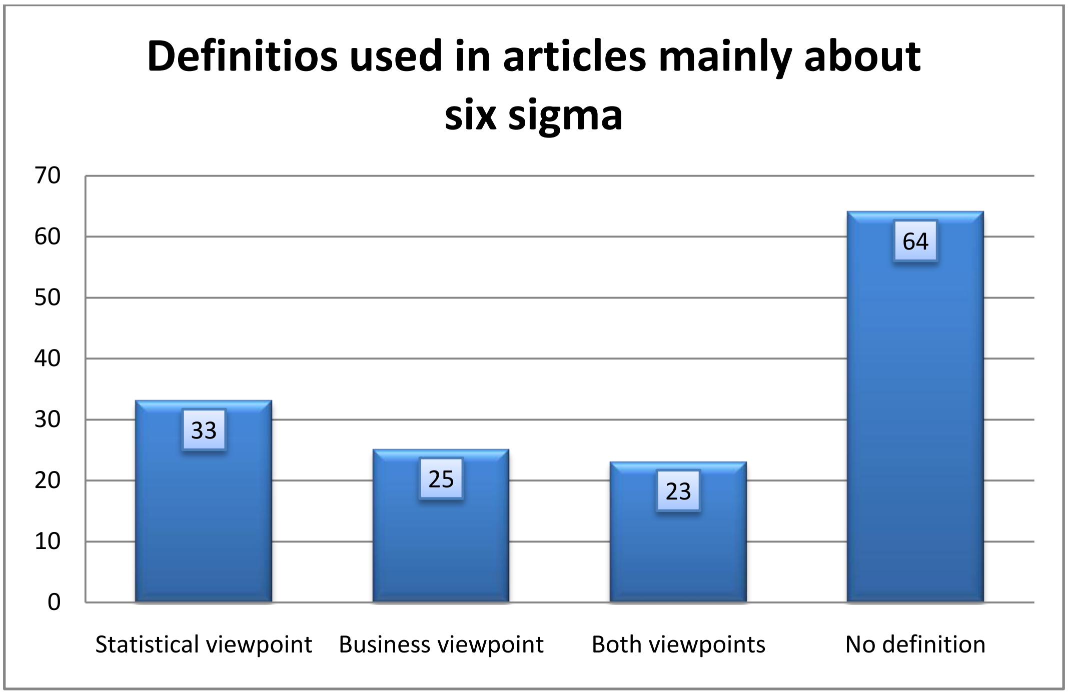


Figure 4.22 Definitions used in articles mainly about six sigma

As the figure suggests, majority of the authors prefer not to offer precise definitions but to provide an insight by giving their methodological framework. 39 of the 64 articles which did not include any definition included at least one “success factor” of six sigma implementation. (Success factors will be discussed in Section 4.13.)

Figures 4.23 and 4.24 show the differences of the viewpoints adopted by article types and author affiliations respectively.

Figure 4.23 demonstrates the considerable difference in the ratios of definition types across case studies and conceptual articles. While case studies apply more to the definitions from the statistical viewpoint, conceptual articles are inclined to use those definitions constituted through a business perspective more.

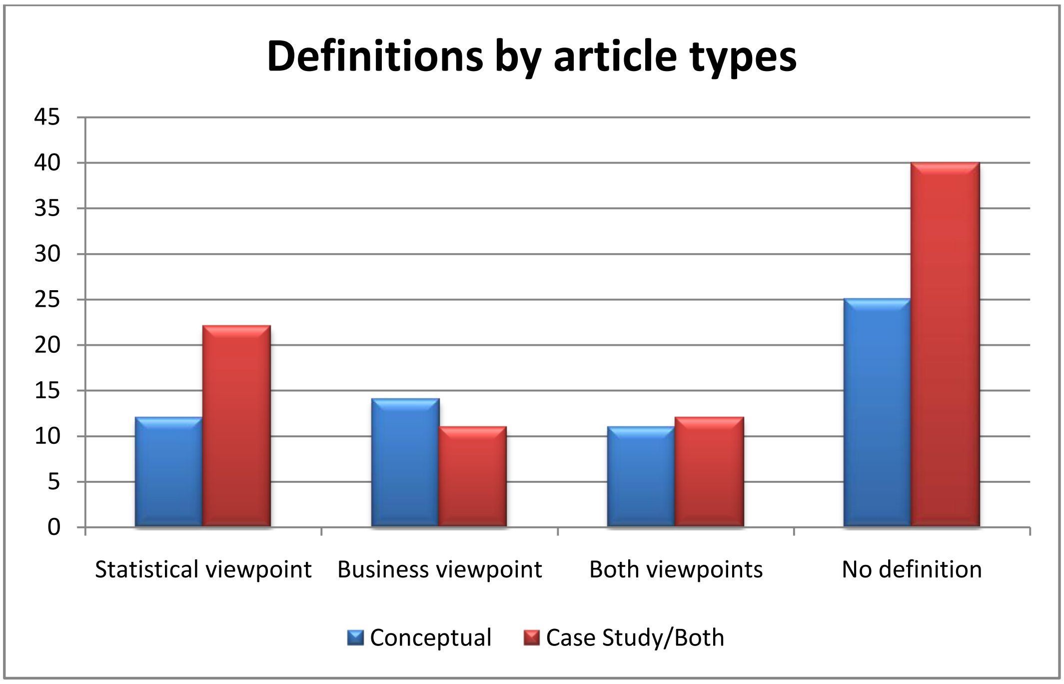


Figure 4.23 Definitions preferred by article types

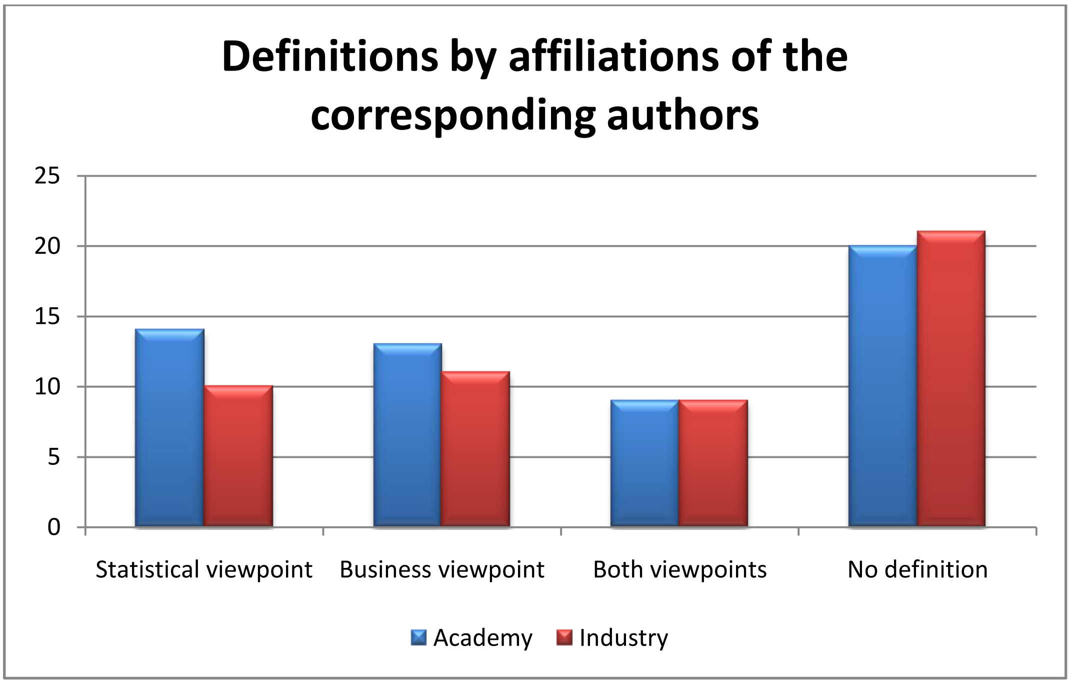


Figure 4.24 Definitions preferred by the affiliations of the corresponding authors

As for the affiliations of the corresponding authors, Figure 4.24 does not provide a basis for claiming that authors from academy and industry prefer definitions from different perspectives. This is surprising in fact, because one would expect to see more statistical definitions from academicians when compared to practitioners who are often accused for their lack of scientific knowledge of statistics.

4.11 DMAIC/DMADV

All tools are applied in a structured and systematic way in six sigma projects, having the ultimate goal of reaching six sigma performance. DMAIC (or DMADV) cycles of six sigma (or DFSS) are the most distinct property of the methodology. One would expect virtually all of the articles about six sigma include this methodology but the actual situation is quite far from that. Figure 4.25 shows the percentage of articles that include reference to DMAIC.

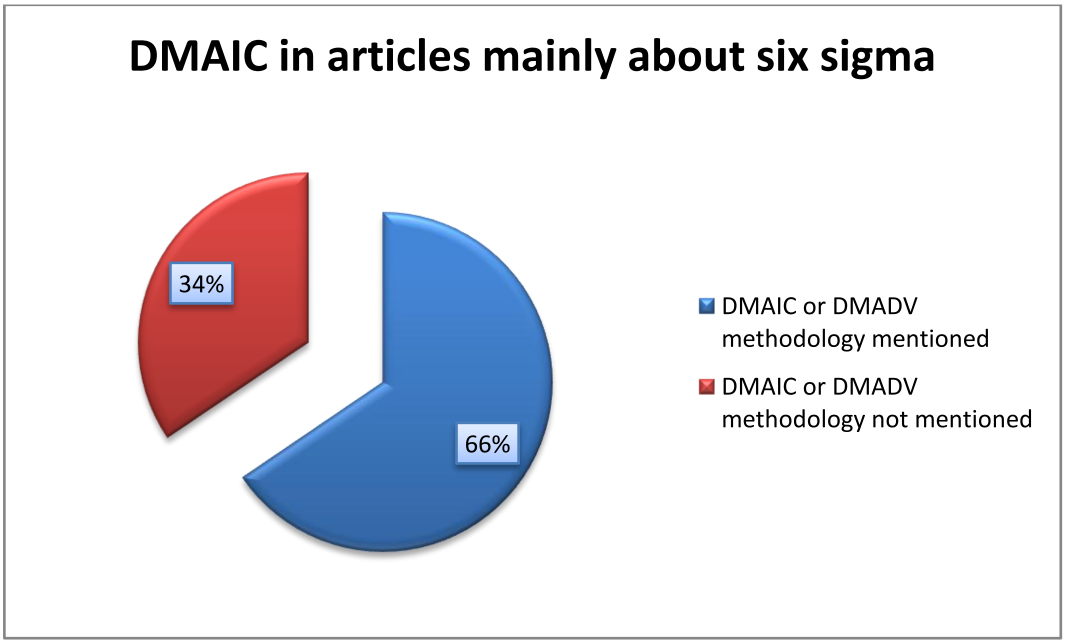


Figure 4.25 Percentage of DMAIC/DMADV inclusion in articles mainly about six sigma

50 of the 145 articles do not mention DMAIC or DMADV at all. Figure 4.26 shows the types of the articles that mention or ignore DMAIC methodology.

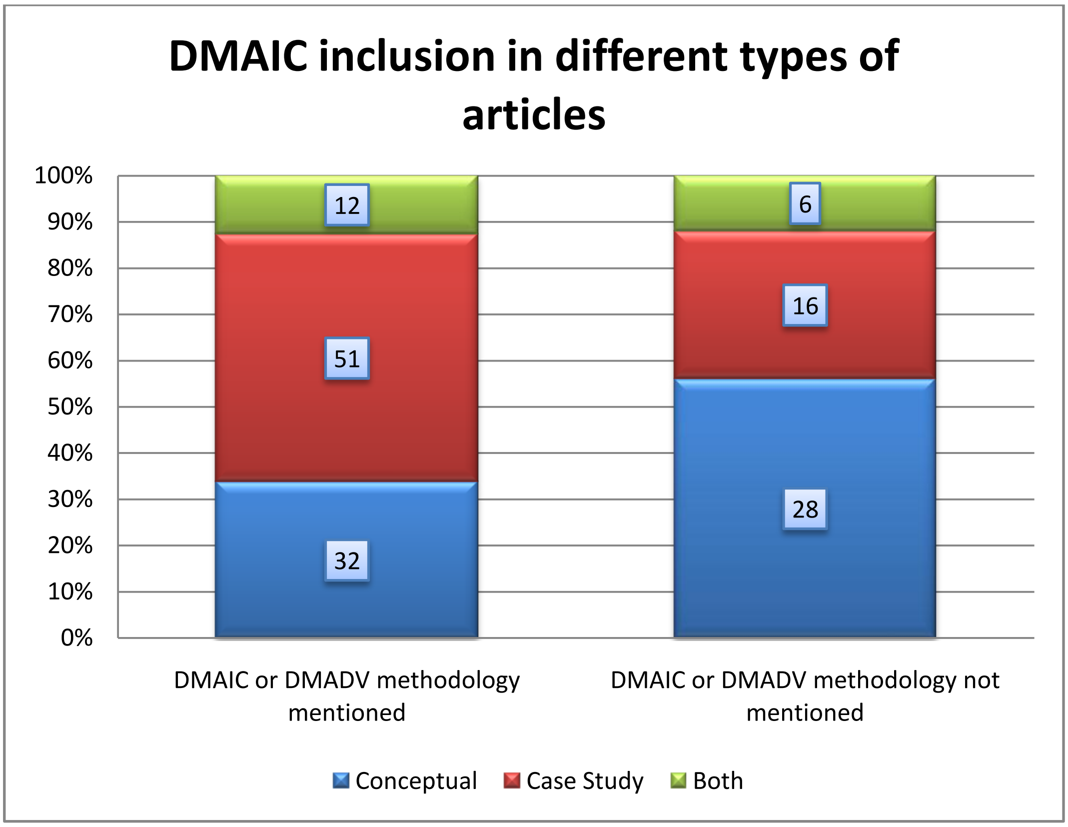


Figure 4.26 DMAIC/DMADV inclusion in different types of articles

More than half of the articles referring to DMAIC are, as expected, case studies. When depicting a case study, the author is expected to speak about the methodology, hence DMAIC cycle. In that sense, it is surprising that 22 articles that include at least one case study (24% of all case studies) ignore DMAIC cycle. The academic character of these case studies is believed to be controversial. Conceptual articles might address a different aspect of six sigma, for instance black belt selection or training programs, and not mention anything about the DMAIC cycle or methodology. Therefore, 28 of the articles that did not mention DMAIC cycle is understandable.

To discuss the difference between academicians and practitioners in this subject, the Figure 4.27 is presented.

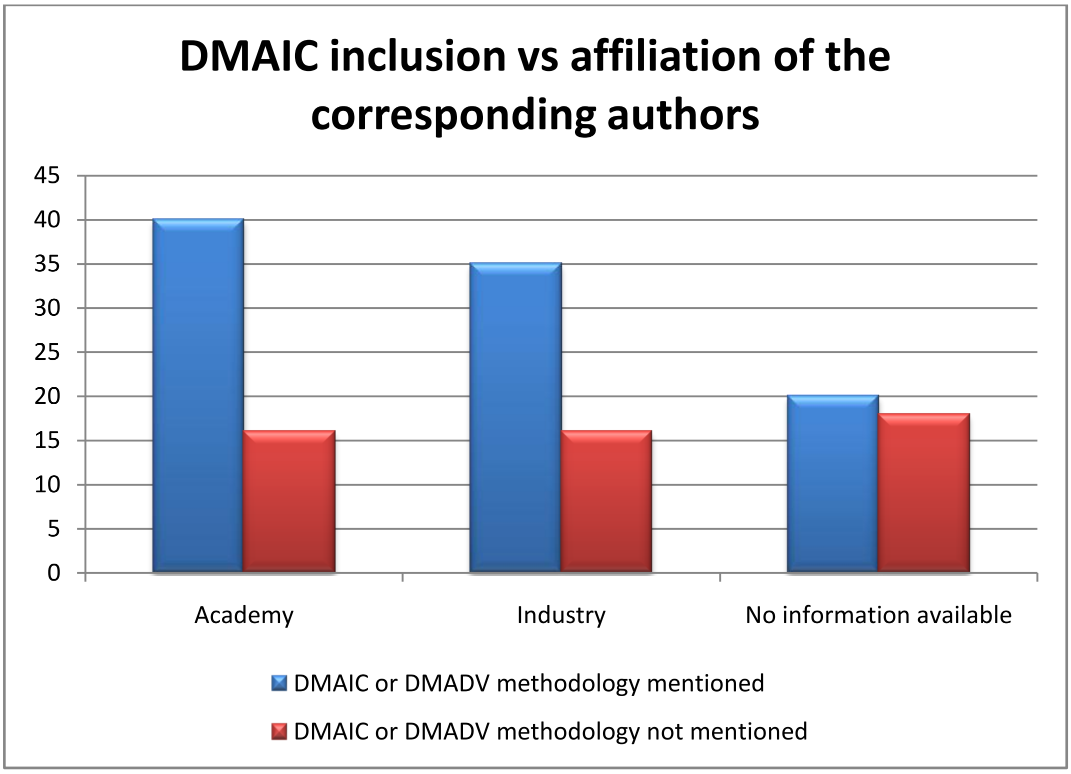


Figure 4.27 DMAIC inclusion vs. affiliation of the corresponding author

According to the figure, although the number of academicians mentioned DMAIC is slightly more than that of industrialists; considering the ratios no conclusions can be reached.

4.12 Reference to Other Quality Initiatives

In the articles, some other quality initiatives and business improvement systems are mentioned in different contexts. In some articles, the history of six sigma necessitated referring to them. In others, they are compared to six sigma, or they are proposed to be used in integration with six sigma initiatives.

An analysis of 208 full-text articles reveals that 29 other quality initiatives are mentioned in 91 articles. Among them, 16 were mentioned only once. Remaining 13 quality initiatives that were addressed in at least two articles are listed in the following table.

Table 4.4 Other quality initiatives mentioned at least in two articles

Quality Initiatives	Times Mentioned
Lean management	39
Total quality management	31
ISO/QS	23
Taguchi - Robust design methods	15
Kaizen	13
Malcolm Baldridge National Quality Awards criteria	9
Enterprise resource planning	6
Business process reengineering	5
Zero defects	5
Quality circles	4
Shainin system	3
Theory of constraints	3
Statistical process control	2

Lean management is the most popular quality initiative in the six sigma literature. Lean principles are generally proposed to be used together with six sigma programs. Nash, Poling, and Ward (2006) argue, for example, that synchronization of lean management and six sigma provides faster results and shorter project times in six sigma projects.

TQM is discussed in several contexts. It is said to be either the first step in quality initiatives in a company which will lead to six sigma initiative in future (Basu 2001, Harrold 1999), or an alternative which compels with six sigma (Hahn et al., 1999, Kumar et al., 2006), or an outworn method embraced and surpassed by six sigma (Pavletic & Sokovic, 2002).

ISO standards are considered together with QS 9000 standards, which are the adaptation of ISO standards to automotive industry. Taguchi’s robust design methodology, Kaizen, and statistical process control, although could be employed within six sigma projects, are put as alternative quality programs by some authors (de Mast et al. 2000, Hinckley & Barkan, 1996) and are included in this discussion.

To see which initiatives are proposed to be used together with six sigma in at least two different articles, please refer to Table 4.5.

Table 4.5 Other quality initiatives which are proposed to be integrated with six sigma

Quality Initiatives	**Times Mentioned**
Lean management	35
Total quality management	11
Taguchi – Robust design methods	9
ISO/QS	7
Enterprise resource planning	6
Kaizen	6
Malcolm Baldridge National Quality Awards criteria	2
Theory of constraints	2

As it can be seen from the table, 35 of the 39 articles that mentioned lean management proposed the integration of the two initiatives. Indeed, the integration of six sigma and lean management is a widely-accepted method in the industry. Kumar et al. (2006) say that lean can be used as a “foundation that allows the tools of six sigma to yield greater benefits”. The article provides toolsets for both initiatives and finds that they use many common tools such as histograms, control charts, 5 whys, etc. Some authors argue that implementing six sigma in a lean environment or after a lean production study is a success factor for successful implementation of six sigma (Nash et al., 2006) In fact, “lean sigma” idea is not only an industry trend. Figure 4.28 shows that at least one-third of the authors who supports lean and six sigma integration are academicians.

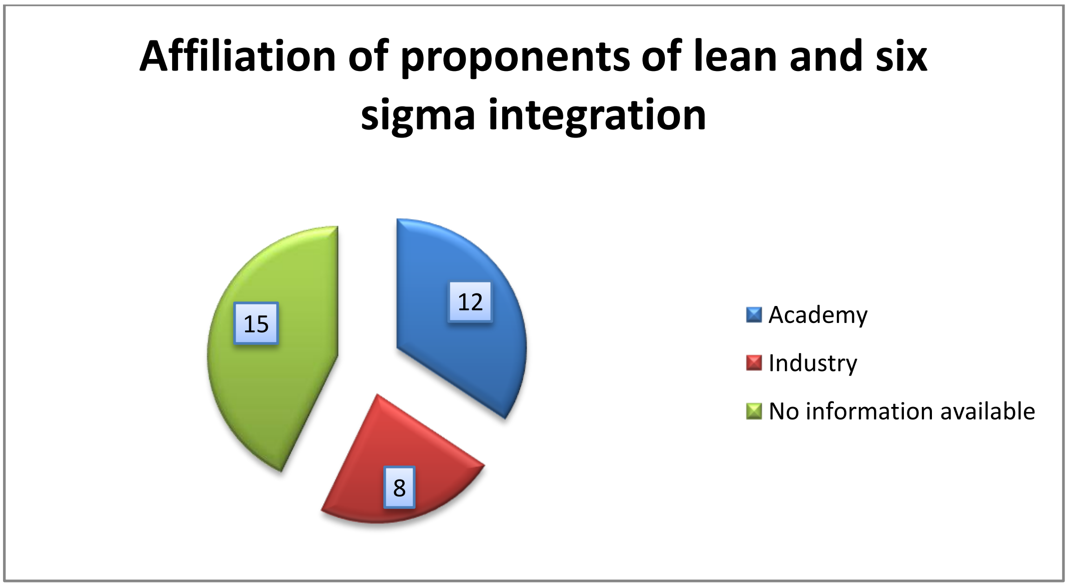


Figure 4.28 Affiliation of corresponding authors of articles that supported lean and six sigma integration

Lean and six sigma integration trend within years is represented in Figure 4.29 below.

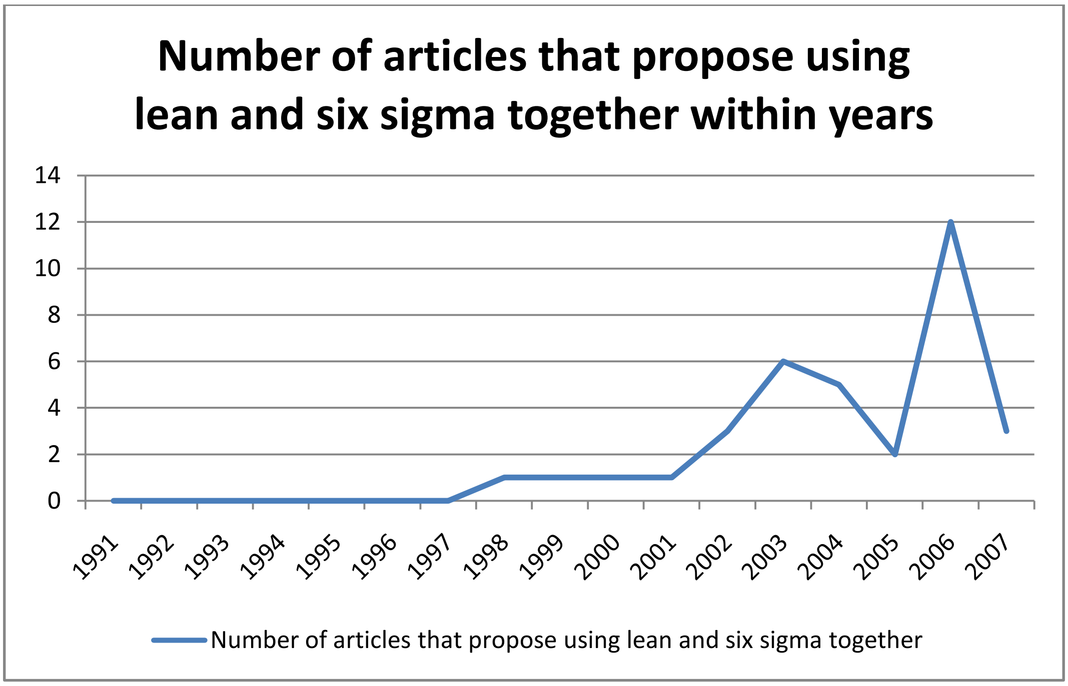


Figure 4.29 Number of articles that propose using lean and six sigma together within years

According to the figure, the first indexed article that defends the lean and six sigma integration was published in 1997. From then to 2003, an increasing trend is observed. Although a clear trend is not visible after that year, the peak in 2006 is a clue for the general acceptance of “lean sigma”. It is early to claim that lean and six sigma integration is an industry standard, but yielding integration practices and more articles standing for “lean sigma” may be expected.

Some articles which are not mainly about six sigma referred to six sigma as an example of a quality initiative in their subjects/abstracts. To find this ratio, Figure 4.30 is constructed. As the figure shows, 22 of the 208 full-text articles that included reference to at least one other quality initiative were not mainly about six sigma. On the other hand, 69 of the 145 (48%) full-text articles that are mainly about six sigma mentioned at least one other quality initiative.

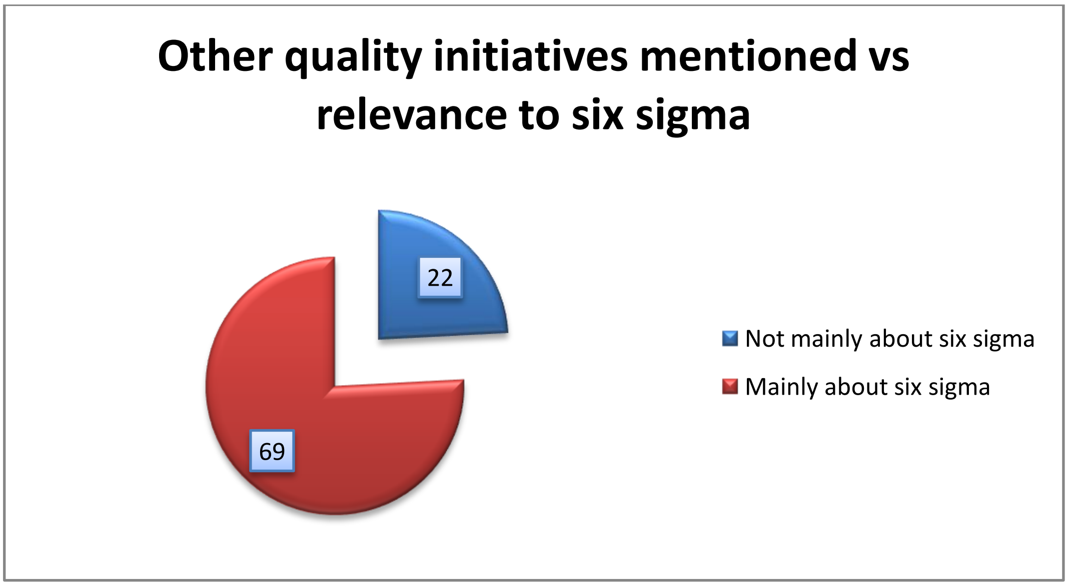


Figure 4.30 Relevance of articles that mentioned other quality initiatives

4.13 Success Factors

Success factors can be described as necessary points for the success of six sigma implementation. 102 of the 208 full-text articles analyzed within the scope of this literature survey mentioned at least one success factor. 32 distinct success factors are identified from the articles. Table 4.6 provides a list of these factors and shows how many articles referred to them.

Table 4.6 Success factors mentioned in articles

Success factor	**Times mentioned**
Management commitment	45
Training	31
Clear performance metrics & integration with business strategy	30
Cultural change	25
Commitment, involvement, empowerment and satisfaction of team members	22
Selecting and training right people	21
Data and fact driven management	20
Customer focus	20
Project selection	18
Involving suppliers / customers in six sigma process	17
Communication and common language	16
Quantified financial impact	15
System for monitoring, measuring and reporting performance	14
Training going together with real projects	11
Statistical software and IT infrastructure	10
Rewards	10
Profound knowledge of processes	8
Not limiting the projects with manufacturing	8
Cross functional teams	8
Goal setting	7
Data quality	7
Measurement system	7
Systemic and innovative thinking	6
Project-focused approach	6
Management objectives deployable to the shop floor	5
Implementing six sigma in a lean environment of after a lean project	4
Six sigma infrastructure	4
Stable performance and quality improvement culture	3
Viewing six sigma as a process rather than a tool	3
Deployment plan	2
Knowing the best practices in the industry	2

Brady and Allen (2006), Goldstein (2001), and Antony and Banuelas (2002) studied success factors and provided shorter lists of 13, 13 and 11 factors. In this piece of work, 32 distinct success factors were identified. Management commitment, training, project selection, customer involvement/focus, supplier involvement; which are the factors number 1, 2, 8, 9, 10 in this study, were the common success factors in all three articles.

A straightforward calculation shows that 49% of all full-text articles include at least one success factor. Only 12 of these 102 articles are not mainly about six sigma. In other words, 90 of 145 articles that are mainly about six sigma (62%) include at least one success factors.

“Management commitment” is underlined by 45 authors (44%). Second and third factors in the table are referred by 30% and 29% of the articles that included at least one success factor. These three factors stand out as the topmost factors that were agreed upon. For a time based analysis of these factors, please see Figure 4.31.

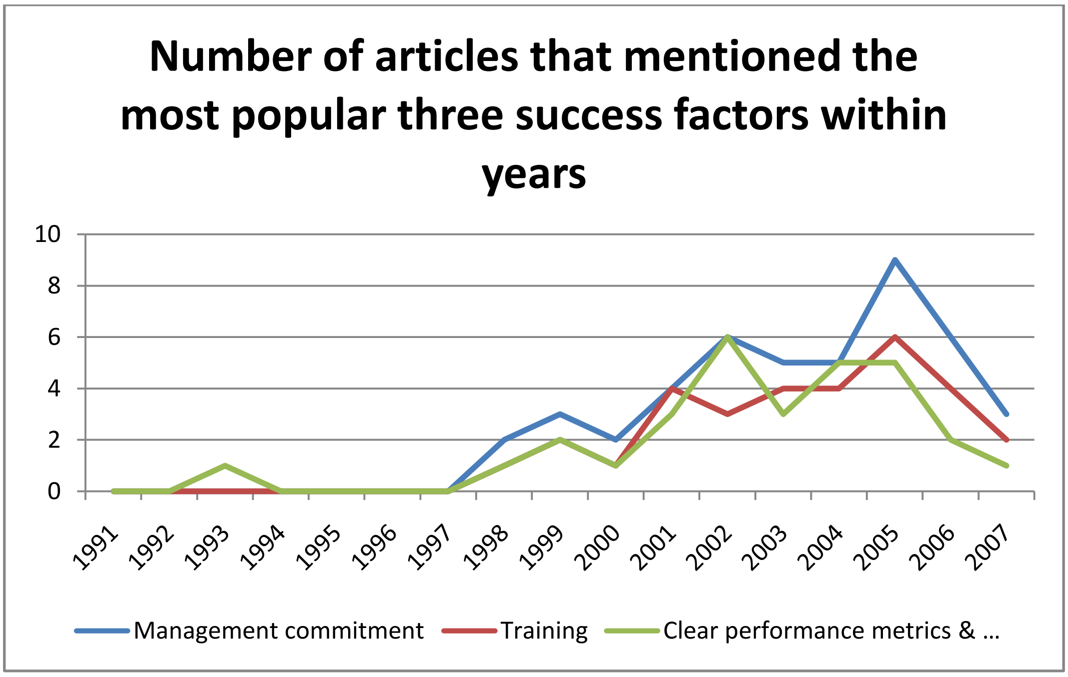


Figure 4.31 Number of articles that mentioned the most popular three success factors within years

Before 1998, these three factors were almost never mentioned. It can be interpreted that enough experience was accumulated and a generally increasing trend is seen from that year on, 2005 being the peak point.

Brady and Allen (2006) note that “customer focus” factor and “bottom line focus” (listed in the table as “quantified financial impact”) are contradicting. Yet, 7 articles in this study mention both of these factors at the same time. Brady and Allen (2006) believe that this contradiction points out the “heuristic nature of articles in general on the subject of success factors”.

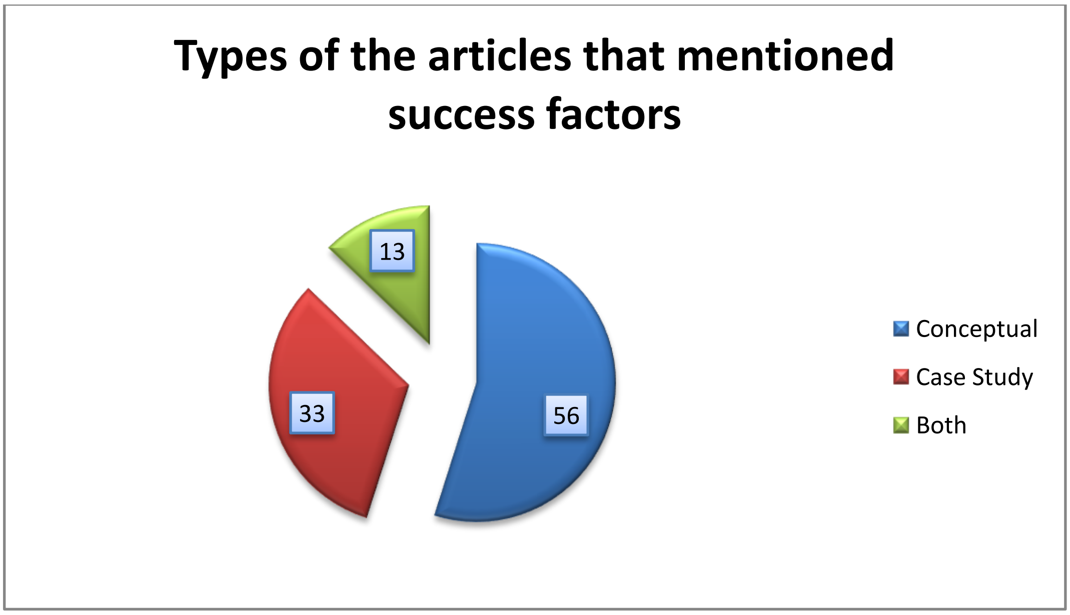


Figure 4.32 Types of the articles that mentioned at least one success factor

Figure 4.32 shows the types of the articles that mentioned at least one success factor. Conceptual articles constitute the majority of the articles that include success factors. Moreover, articles that include case studies touch on to 3.65 success factors on average, while conceptual articles mention 4.23. These averages show us that conceptual articles are more concerned with success factors.

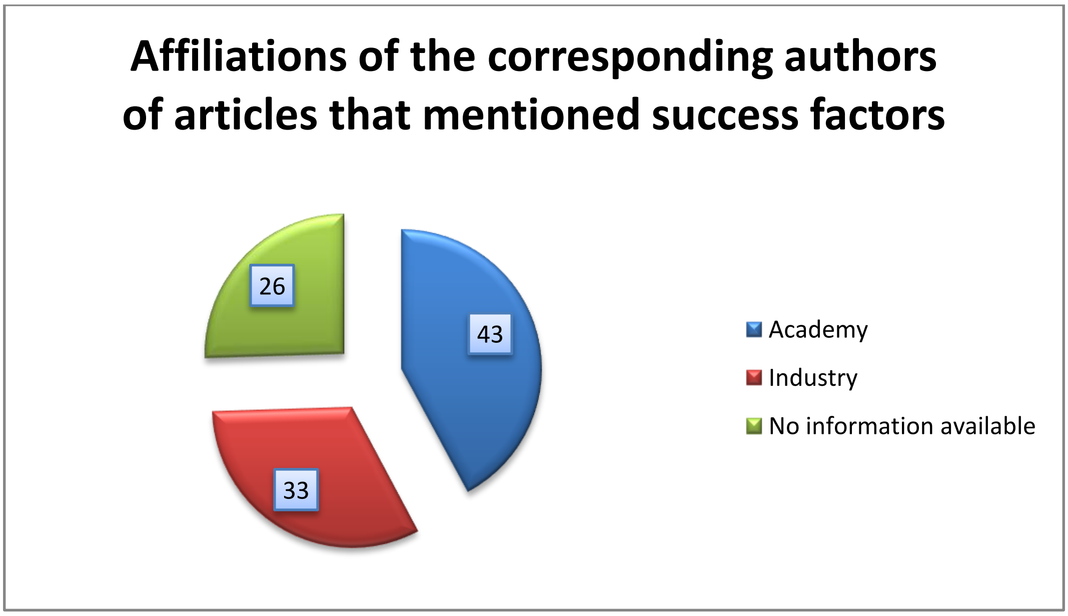


Figure 4.33 Affiliations of the corresponding authors of articles that mentioned at least one success factor

Figure 4.33 about the relation between success factors and affiliations of the corresponding authors show that, academicians give more details about success factors of six sigma implementation. This is surprising, because authors from industry are practitioners, who are expected to give more tips learned during hands-on experience.

Figure 4.34 repeats the same analysis in success factor level. According to the figure, five most popular success factors are referred primarily by academicians. “Six sigma infrastructure” factor is solely used by them, while “measurement system” and “goal setting” factors are dominated.

On the other hand, “training going together with real projects”, “rewards”, “data quality”, and “systemic and innovative thinking” factors are dominated by authors from industry.

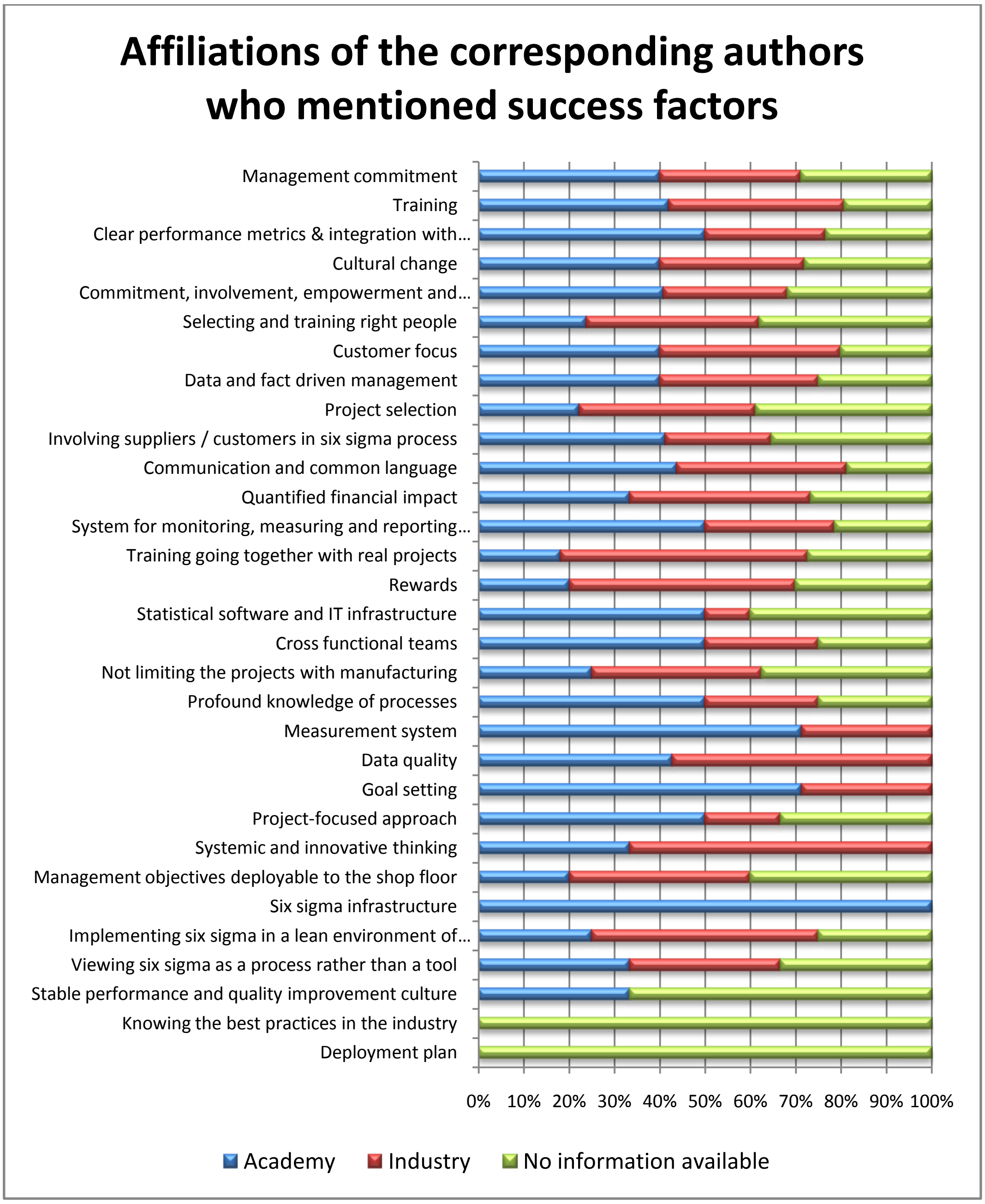


Figure 4.34 Affiliations of the corresponding authors who mentioned success factors

4.14 Criticism about Six Sigma

Some articles in the literature addressed negative aspects of six sigma and criticized it, or at least rephrased some common criticism although the author himself/herself did not agree.

In 208 full-text articles, a total of 37 articles include at least one critique. Critiques mentioned at least in two different articles are listed in Table 4.7.

Table 4.7 Critiques mentioned at least in two articles

Critiques	**Times Mentioned**
Only an advertisement tool	5
Doesn't allow for random research and innovation, process map dependent	5
No original tools introduced	5
Cumbersome and unfathomable	4
Presented as a panacea for all business ills	4
Doesn't consider the effects of quality of working life	4
Internally focused	4
Not fast enough	3
Standard goal for all processes	2
Confusing name	2
Claims all defects to be equal	2
Considers doctors as economic actors	2

As the table shows, the idea that six sigma is simply a repackaging and marketing of old tools and concepts by quality consultants in order to make more money (Stamatis, 2000) is the most frequently mentioned critique (Hahn, 2002; Raisinghani et al., 2005). Another important one is that six sigma is a method of reducing the variation in existing processes without assessing the correctness of them. When a new product or process is demanded, the primary forces are innovation and invention, which are not believed to be incorporated with six sigma methodology (Choo, Linderman, & Schroeder, 2007).

Besides the critiques given in the table, 22 others are mentioned, each only once in different articles. Among them, the following stands out: “Defect and opportunity definitions not clear” (Raisinghani et al., 2005), “creates elite black belts disconnected to shop floor” (Smith, 2003), “too much emphasis on quantifying payoffs” (Hahn, 2002).

For the types of articles that included criticism, Figure 4.35 can be seen.

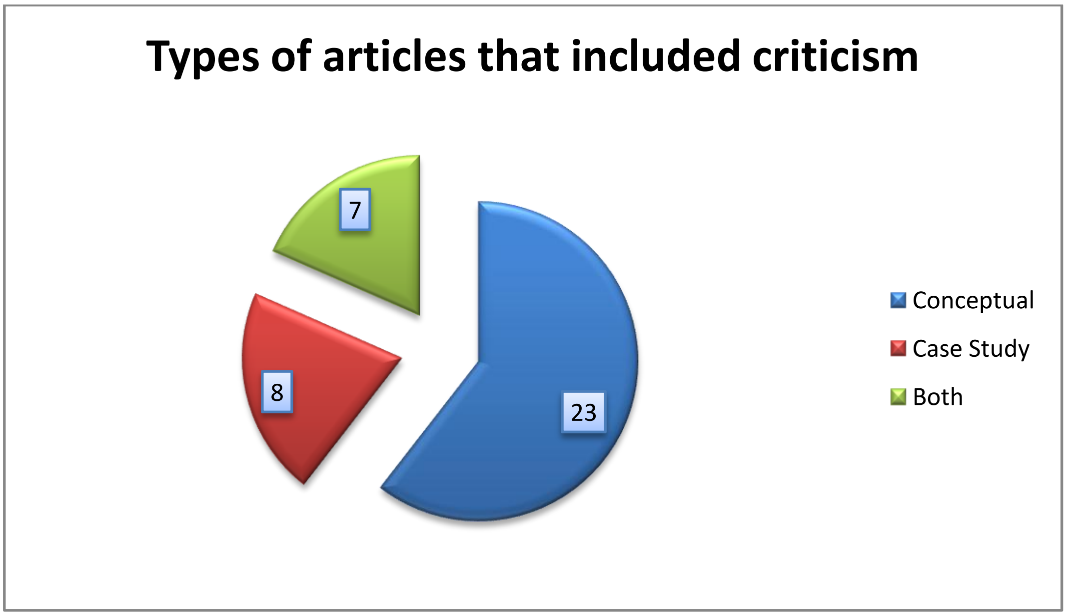


Figure 4.35 Types of articles that included criticism

23 of the 38 articles that included criticism are conceptual. Conceptual articles are expected to discuss six sigma theory and practice at a higher level and are expected to include more criticism, which is consistent with the figure.

The very first critique identified in the six sigma literature is "the goal being too hard to reach" (Hinckley & Barkan, 1996). It is interesting that after that one, the same critique was never mentioned again. It can be argued that practitioners of six sigma methodology mastered it in years and reaching six sigma goal became easier. On the other hand, "panacea for all business ills" critique is mentioned three times in 2006 and 2007 (Antony, 2007; Kwak & Anbari 2006; Tang, Goh, Lam, & Zhang, 2007). This shows that six sigma practices proved unsuccessful in solving certain types of business problems and other approaches are necessary for these.

For the affiliations of the corresponding authors of these 38 articles that include at least one critique, see Figure 4.36.

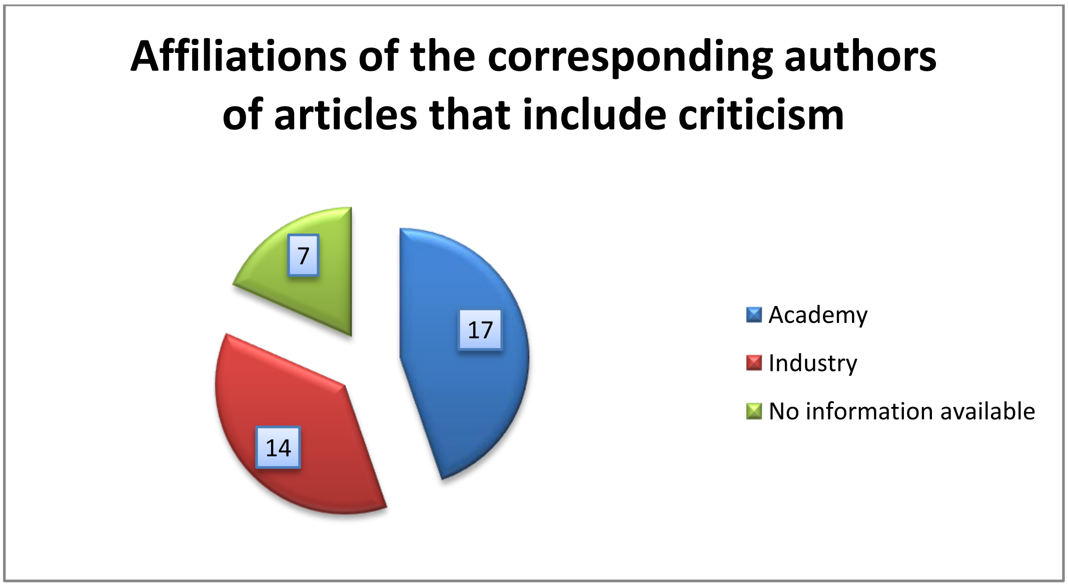


Figure 4.36 Affiliations of the corresponding authors of articles that include criticism

The figure shows that 17 academicians criticized six sigma or mentioned a critique about it. Critical attitude is an integral part of scientific method; therefore academician majority in the figure is not surprising.

4.15 Ideas about the Future of Six Sigma

In 23 articles (11% of all), authors stated their ideas, expectations, and predictions about the future trends in six sigma. 20 different ideas are identified. Table 4.8 provides a list of such ideas mentioned at least twice.

Table 4.8 Ideas about the future of six sigma, mentioned at least in two articles

Ideas about the future of six sigma	**Times Mentioned**
Less applications in manufacturing, more in service sector	4
More user-robust tools	3
Evolution from defect/cost reduction to value creation	3
Engagement of academic institutions in six sigma education	3
Further use of neural networks and fuzzy logic	3
Web-based training programs	3
E-manufacturing and e-business effects on six sigma	2
Advances in software, hardware and network technologies to bring easier and cheaper implementations	2

The table shows that the most popular idea is that six sigma will be used more and more in service sector. In fact, the analysis on the sectoral coverage of articles in section 4.9 showed that the number/ratio of articles related with service sector possessed an increasing trend. On the other hand, the decrease trend in the manufacturing sector was a matter of discussion.

User-robust tool development is another popular expectation. Hahn and Hoerl (1998) say that the new era is the era of “statistics without statisticians”. This holds for six sigma: Most of the six sigma practitioners are not statisticians or statistically trained before a six sigma study. Therefore, new statistical tools or software which can be used by non-statisticians with ease is a reasonable expectation.

Engagement of academic institutions in six sigma education is expected in 3 articles. Some universities in the US, like Arizona State University (Montgomery et al., 2005) and Virginia Tech (Anderson-Cook, Patterson, & Hoerl, 2005) have started six sigma training programs. However, such an attempt in Turkey is not announced yet. As the subject gains wider acceptance in Turkish industry and as this phenomena affects the number of academic studies, which is discussed in section 4.3, such a development might be expected in Turkey too.

Most of the other ideas on the future of six sigma are related with advances in technology and their effects on six sigma.

The affiliations of the corresponding authors that mentioned at least one idea about the future of the six sigma is shown below.

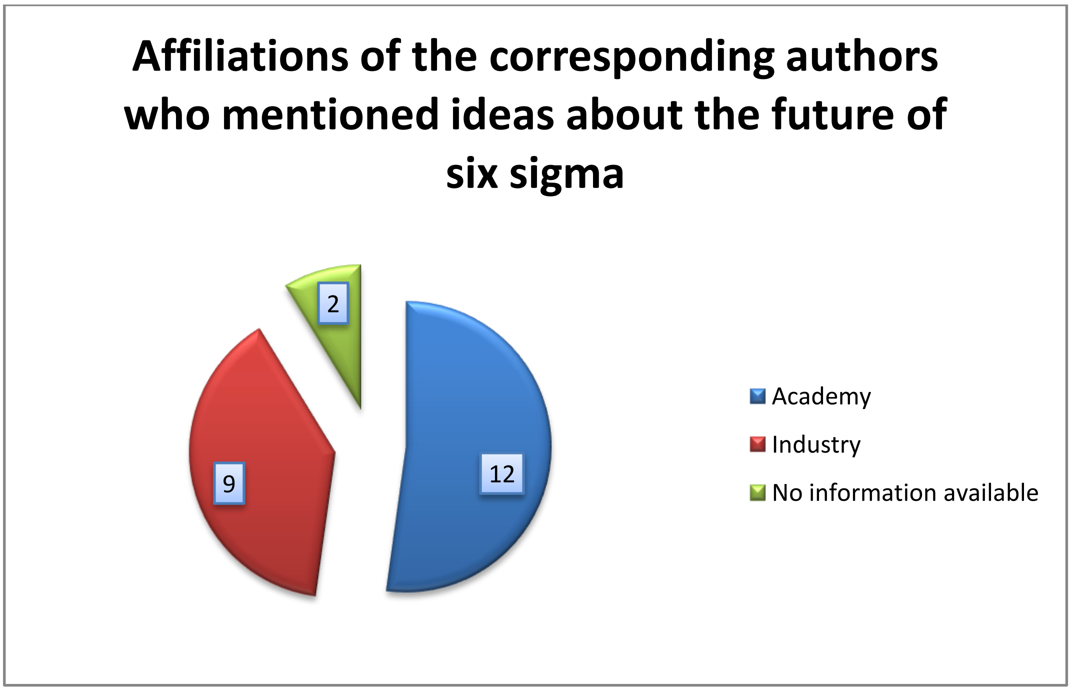


Figure 4.37 Affiliations of the corresponding authors of articles that included at least one idea about the future of six sigma

It is interesting to note that academicians constituted slightly more than half of the set. Since they are considered as the theoreticians, and authors from the industry as the practitioners, an academic domination in the figure could be expected. However, ideas on the future of the subject come from both parties in similar percentages (52% vs. 39%), showing that practical information can be very fruitful when making theoretical predictions.

On the other hand, Figure 4.38 reveals that the overwhelming majority of articles that present predictive discussions are conceptual. This is in accordance with the expectation, because conceptual articles provide more theoretical framework which is necessary for discussions about the future of the methodology.

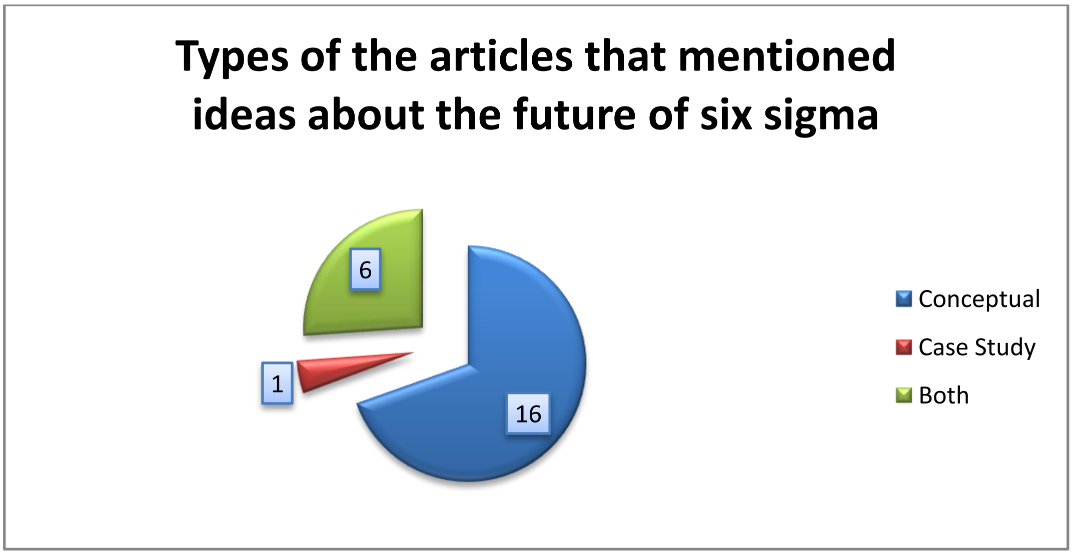


Figure 4.38 Types of the articles that mentioned at least one idea about the future of six sigma

4.16 Challenges

Some authors mentioned certain challenges that can be/are faced during a six sigma implementation. 13 different challenges were identified at least twice in 33 of 208 full-text articles. These challenges are shown in Figure 4.39.

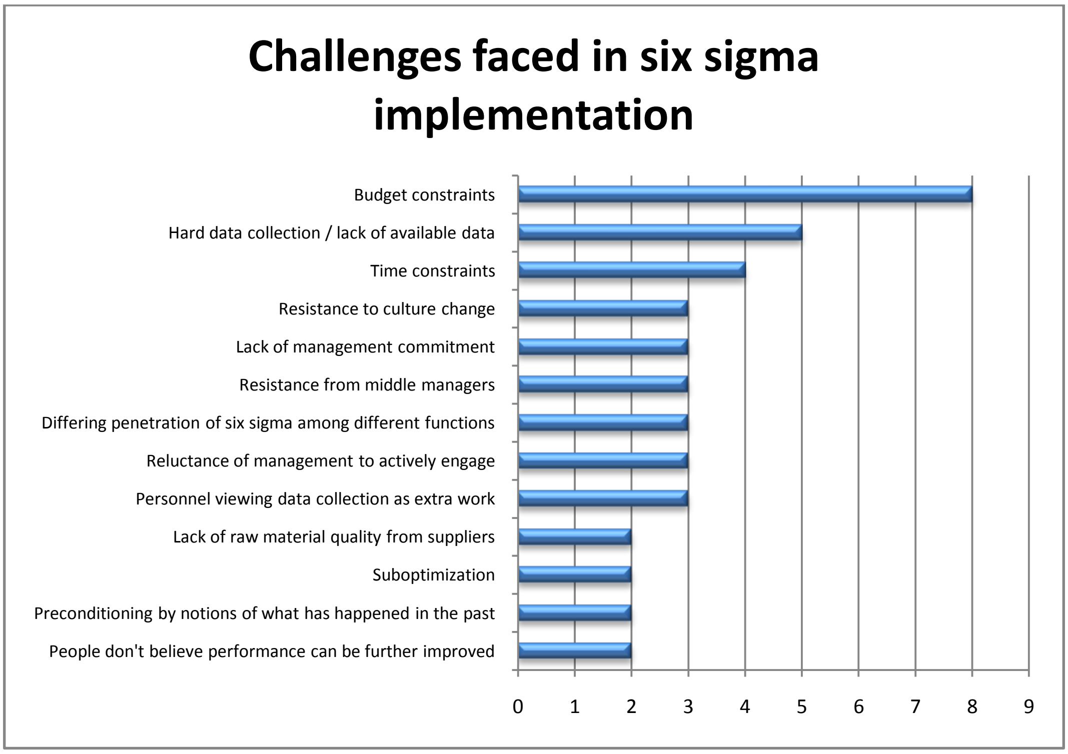


Figure 4.39 Challenges mentioned in at least two articles

Budget constraints are the most common problem. Many firms believe that six sigma is an expensive initiative (Sokovic & Pavletic, 2007), which makes sense when the cost of training programs and personnel allocated to six sigma projects for full-time are considered. However, if these costs are acknowledged, high returns are expected as cost reductions that are going to be realized later, such as lower scrap and rework costs, lower warranty claims, etc. Moreover, the previous section included ideas aiming at more affordable implementation in the future. E-training programs, cheaper-to-train white belts, and similar low-cost solutions may overcome this problem in the near future.

Lack of available data is another common challenge, which sometimes might be a result of non-standard processes or lack of a successful measurement system. In this case, a measurement system should be designed, its validity should be checked with a measurement system analysis study, and data collection process should start. Six sigma is a data-driven and thus data-sensitive methodology[12]. Availability and quality of data used in six sigma practices are of vital importance.

It is interesting that "resistance to culture change" is mentioned in only 3 articles. This constraint is probably the hardest to overcome, and the most dangerous because it triggers other problems and leads to certain failure. The reason why it is mentioned only 3 times is believed to be that it is mentioned as a success factor so often. Success factors and challenges may be complementary in this way.

Besides the challenges given in the figure, there are 12 others which are mentioned only in a single article. Among them, "poor project selection" (Caulcutt 2004), "people not convinced that six sigma is suitable for the organization" (Park & Gil, 2006), and "Hawthorne effect[13]" (Frankel et al., 2005) can be listed.

[12] A humorous motto of six sigma practitioners is "In god we trust; else bring data!"

[13] Hawthorne effect is described as "merely being chosen to participate in a study may improve workers' productivity" in Brittanica. (Brittanica Concise Encyclopedia, 2007)

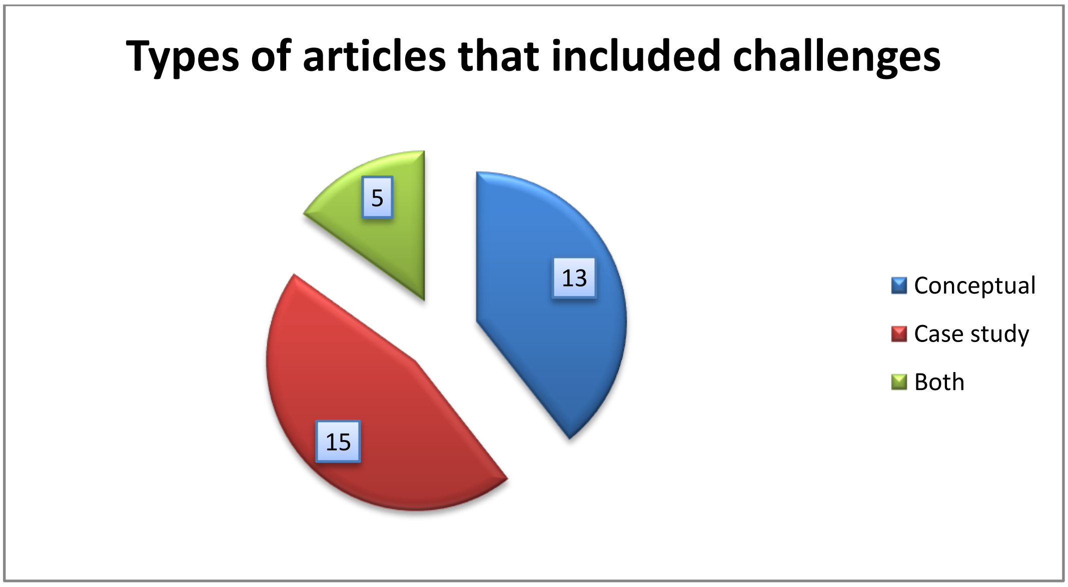


Figure 4.40 Types of articles that included challenges

Figure 4.40 shows that 20 of the articles that mentioned challenges include at least one case study. However, it is interesting that 13 conceptual articles mentioned challenges that might be faced during a six sigma implementation. Challenges are tied to implementation; hence the case study majority is an expected result.

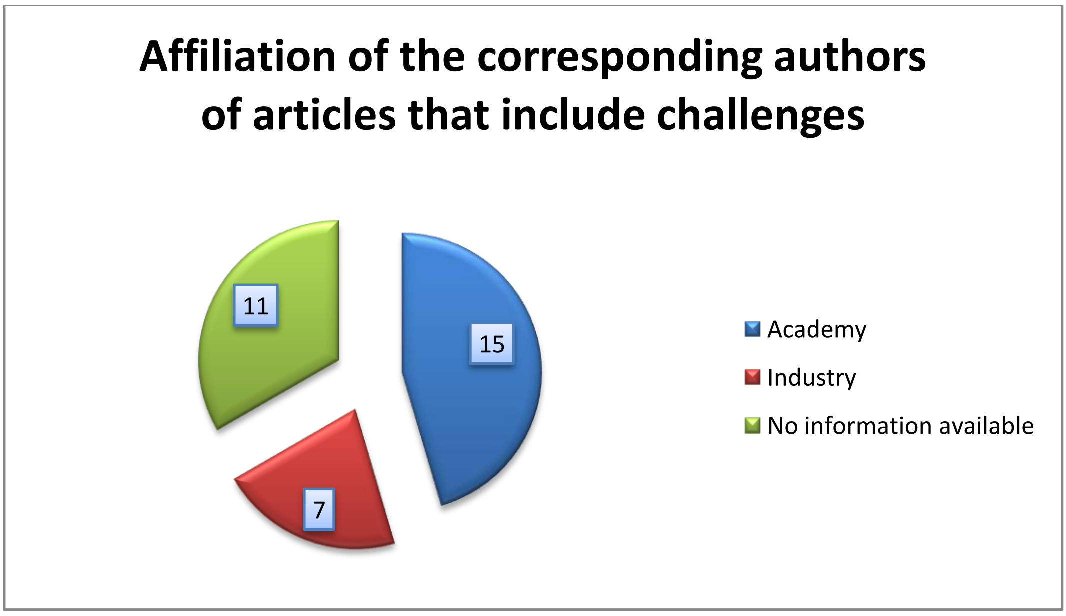


Figure 4.41 Affiliations of the corresponding authors of articles that included challenges

The analysis about the affiliations of corresponding authors, shown in Figure 4.41, yields interesting results. Authors from industry, who have more hands-on experience, are expected to say more about probable or real life challenges. However, academicians gave better details about the problems that can be observed in real life implementation.

Figure 4.42 shows the change in the number of articles that mentioned challenges within years. According to that figure, most challenges were discussed between years 2003 and 2006.

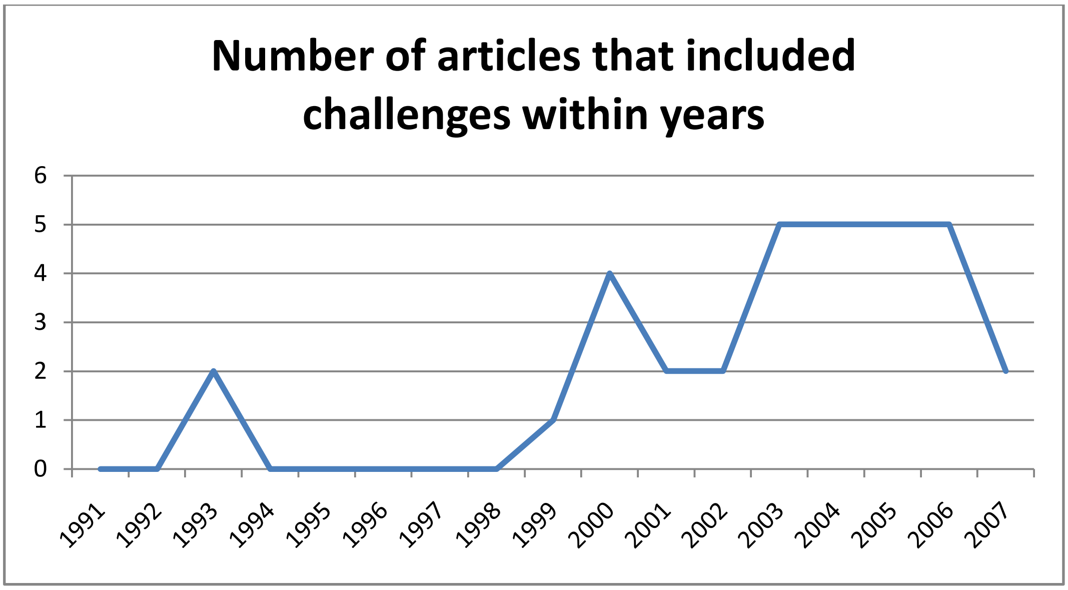


Figure 4.42 Number of articles that included challenges within years

4.17 Performance Measurement

In the articles, the performances of six sigma implementations are evaluated in terms of certain metrics. Since six sigma puts emphasis on quantifiable payoffs, the success is sometimes measured by monetary metrics. Other metrics commonly used in the literature are reduction in variation, lower cycle time, higher rolled throughput yield, lower operating costs, increased use of a service, etc.

The usage frequencies of the most popular metrics are shown in Figure 4.43.

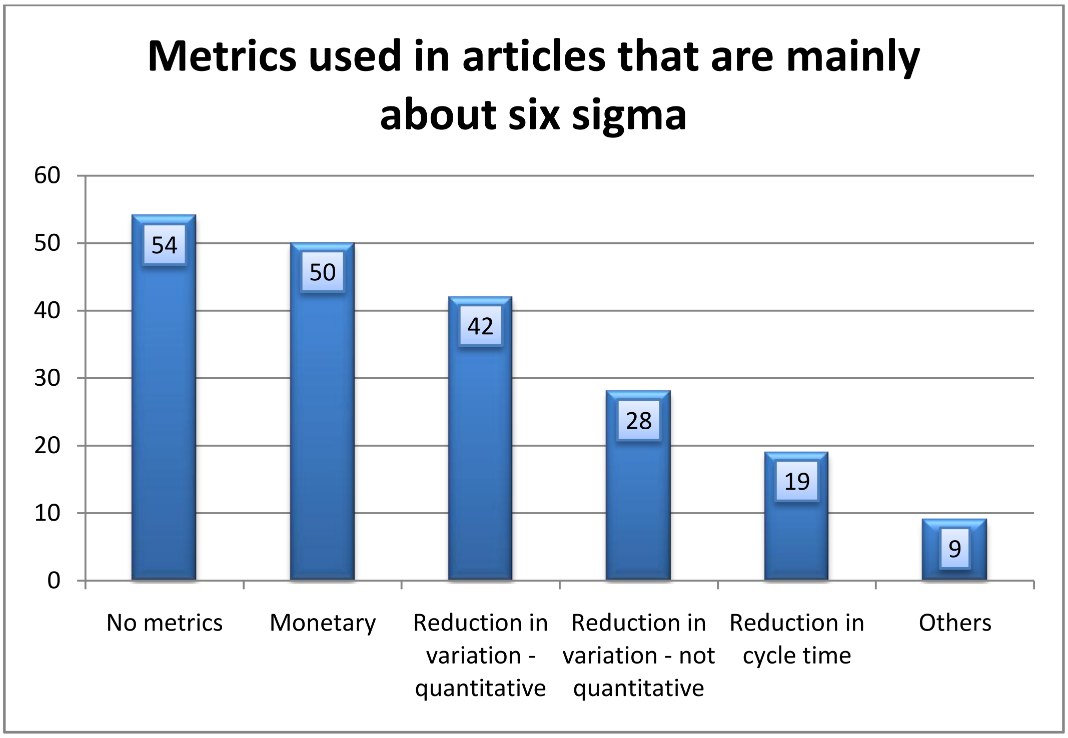


Figure 4.43 Metrics of six sigma implementation in articles mainly about six sigma

As the figure shows, measuring six sigma success in terms of dollars is the most popular approach. However, very few articles provide a scientific calculation of the savings or gains claimed (Brady & Allen, 2006). Moreover, it is not studied in any of the articles how different results would be reached using different approaches.

Besides quantitative metrics, some articles claim reduction in variation but do not give quantitative information about sigma level, defects per million opportunities etc. There are 28 articles that prefer this, as shown in the figure. 19 articles claim success in reduction of cycle time, which is in essence the aim of lean manufacturing. (10 of them proposed integrating lean and six sigma) Other kinds of metrics are rarely used.

The more metrics are provided and reasoned, the more ideas an article gives about the six sigma application. This fact gains more importance in case studies. For an analysis of the metrics used in case studies that are mainly about six sigma, please see Figure 4.44.

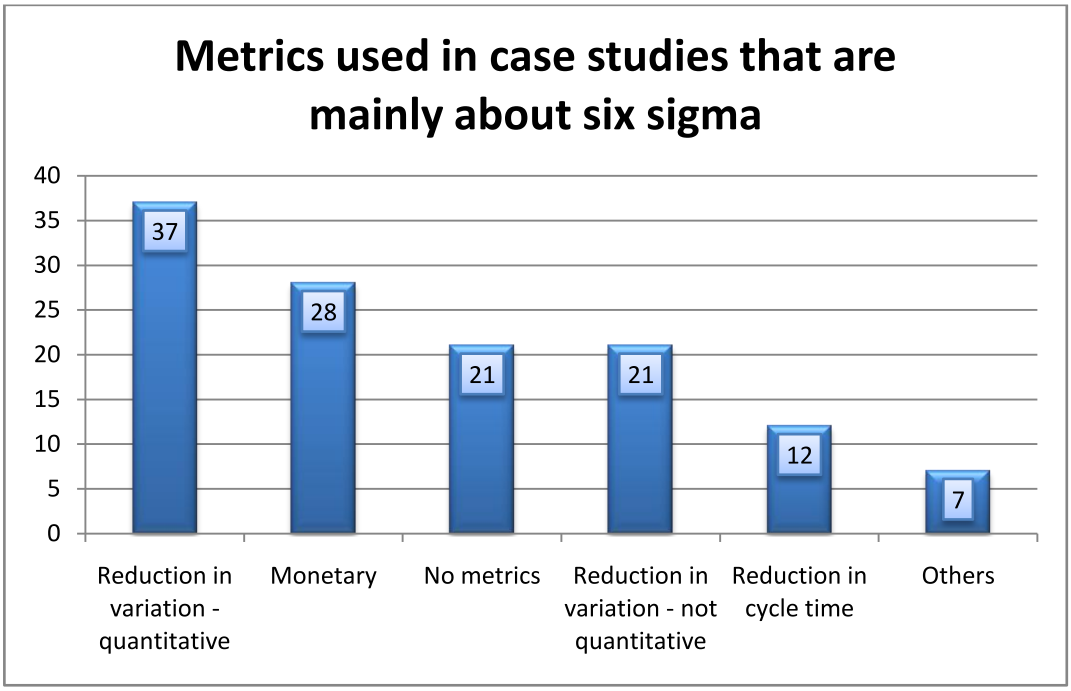


Figure 4.44 Metrics of six sigma implementation in case studies mainly about six sigma

As the figure shows, 21 of the 85 case studies that are mainly about six sigma did not provide any means for measuring the success of the practice. For case studies, the most frequently used one is quantitative variation reduction metric, which increases the academic character of a study. Non-quantitative metrics or no metrics at all in a case study shows that the article depends on anecdotal information which is not scientifically supported by numbers. Only exception for this might be confidentiality agreements between authors and companies, which limit the information open to public. In the presence of such agreements, the authors might be prevented from giving quantitative details.

28 of the case studies used more than one metric, for illustration used monetary metrics and cycle time reduction, at the same time. Since a change in monetary metrics is nothing but a function of changes in other metrics plus the unit costs of certain resources; they are expected to be used together with others in an academic article. However, only 7 case studies included monetary metrics.

Figure 4.45 shows further analysis of metrics with respect to the affiliations of the corresponding authors.

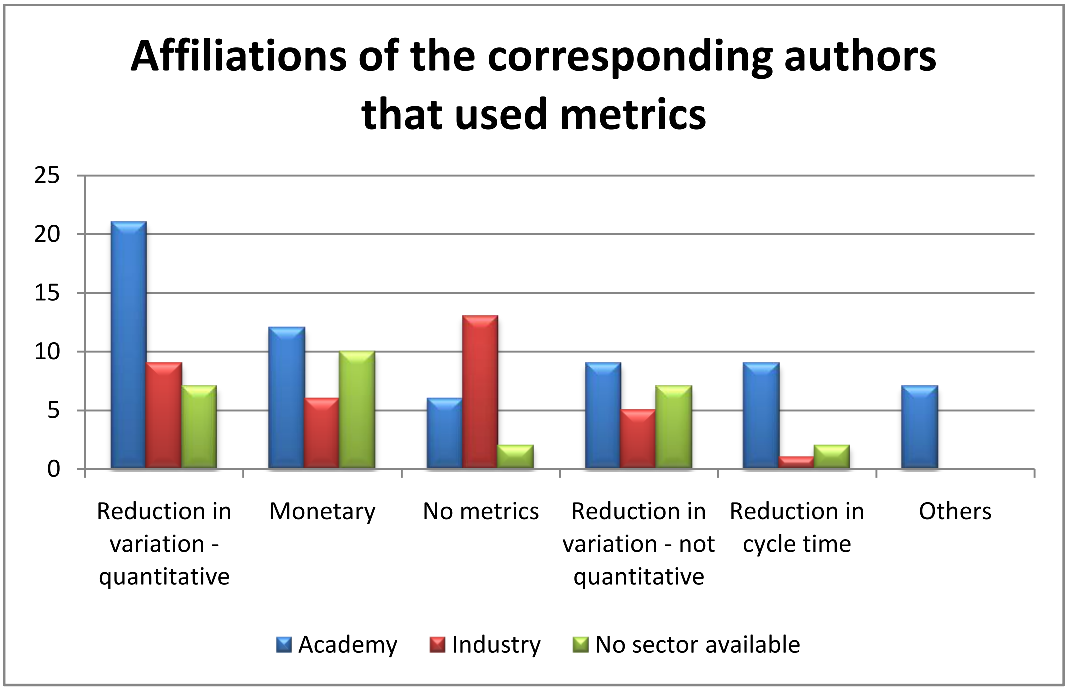


Figure 4.45 Affiliations of the corresponding authors that used metrics

According to the figure, academicians tend to use quantitative metrics of success (sigma level, defects per million opportunities, number of defects etc.) more than industrialists. Authors from industry avoided giving metrics in 13 articles, which has a negative impact in the academic character. It is only academicians who used different metrics ("others") in order to represent the outcomes of their studies. The 9 articles that included other metrics than the categories mentioned belong to authors form academy. These metrics include increase in rolled throughput yield, lower operating costs, reduced waste and so on. Metrics about the reduction of cycle time constitute another group almost always used by academicians. The tendency of academicians to put forward the value and outcomes of their studies made this group use different kinds of metrics, increasing the comprehensibility of the practices.

4.18 Tools

The usage of statistical tools and methods in the six sigma literature is analyzed. A predetermined list of tools is not used and all the tools are identified from the contents of articles. Figure 4.46 is a Pareto chart of tools used in the articles that are mainly about six sigma.

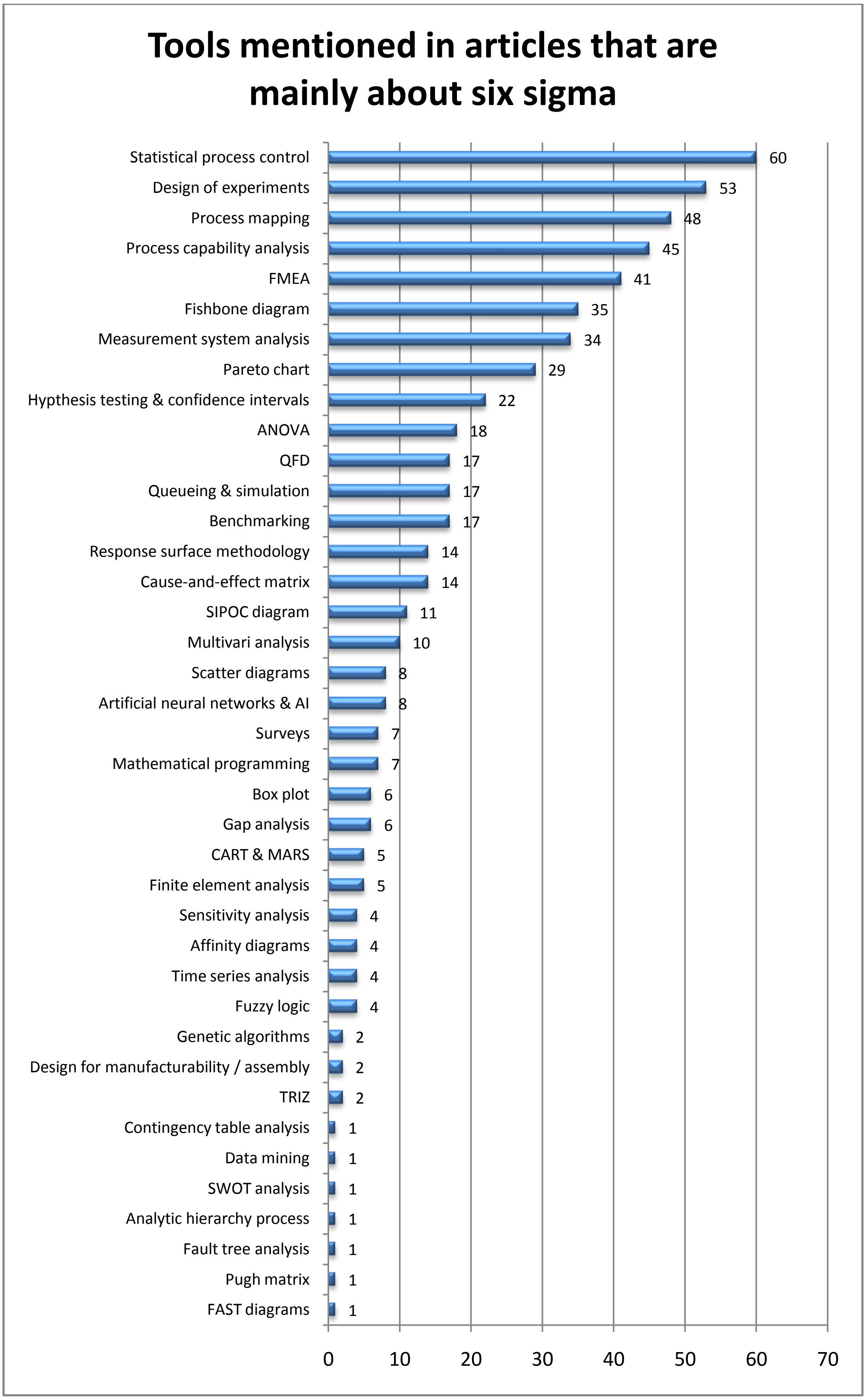


Figure 4.46 Tools mentioned or used in articles mainly about six sigma

The figure shows that process mapping, which is an essential part of six sigma practice, and process capability analysis, which is used in computing the sigma ratio, are the most popular tools in the literature. When the inevitability of these tools in a six sigma practice is considered, these results are expected. Tools that necessitate a certain kind of infrastructure, and that are widely used in the industry as standalone tools, are popular in six sigma context too. Examples of this group include statistical process control (SPC), design of experiments (DOE), failure mode effects analysis (FMEA), quality function deployment (QFD), and measurement system analysis (including gauge repeatability and reproducibility analysis). Besides these, simple visual tools like cause and effect analysis (widely known as fishbone or Ishikawa diagram), Pareto charts, scatter diagrams, and box plots, are the third category that has extensive utilization in the articles.

Some relatively new tools are being used, like artificial neural networks, artificial intelligence (AI), fuzzy logic, and genetic algorithms. Wider use of these tools might lead to important achievements in the near future.

On the other hand, 40 articles that are mainly about six sigma mentioned no tools at all.

The same analysis is repeated for the articles that contain at least one case study in Figure 4.47.

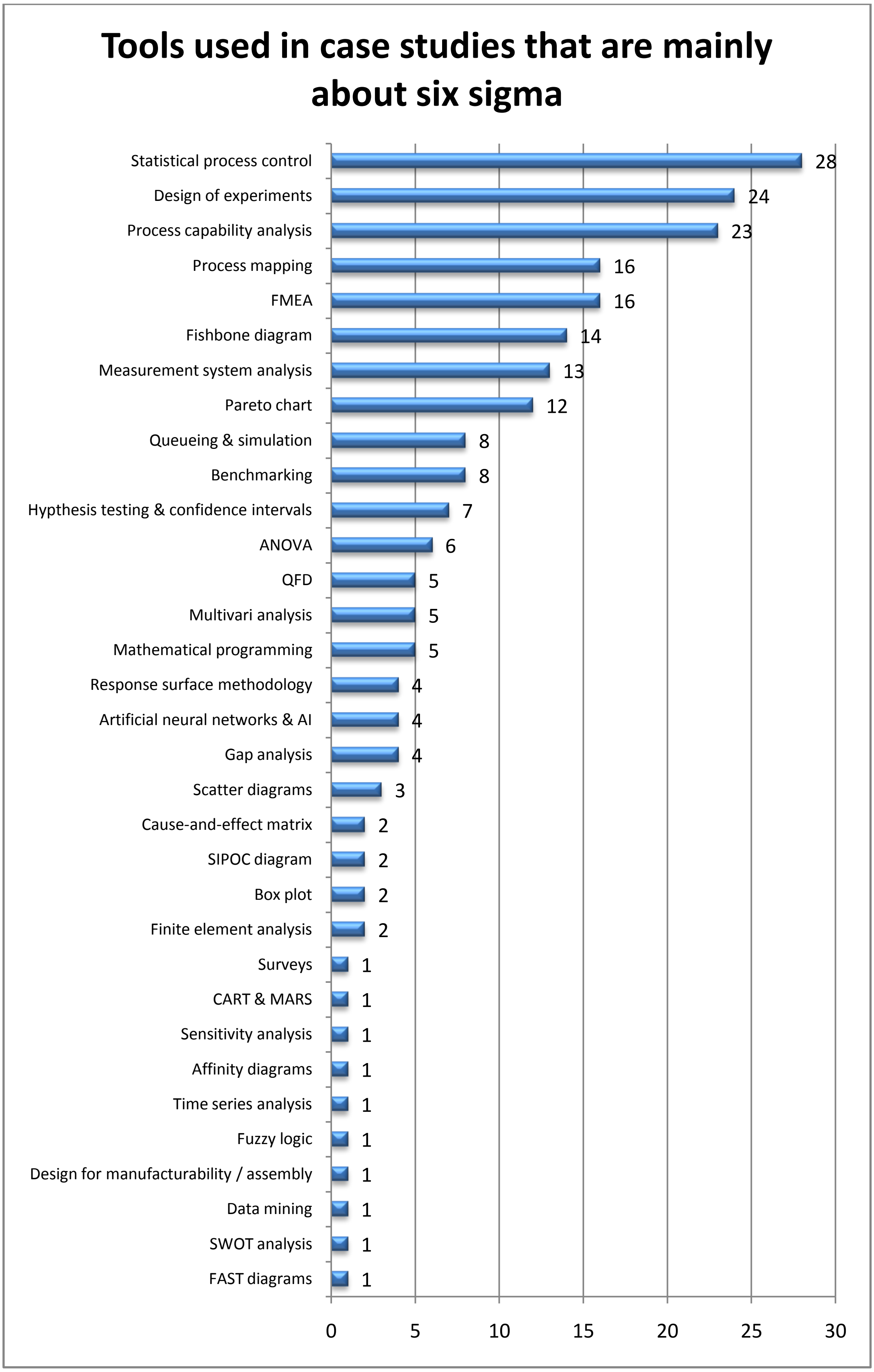


Figure 4.47 Tools mentioned or used in case studies mainly about six sigma

The figure shows that the results are not considerably different. Only six tools were not used in any case study, but were used in conceptual articles. These include pugh matrix, fault tree analysis, analytical hierarchy process, contingency table analysis, TRIZ, and genetic algorithms.

On the whole, 265 tools are used in 84 (2.65 on average) case studies that are mainly about six sigma. 32 case studies do not mention the name of any single tool, which is surprising. Ignoring these articles, the average number of tools used in an article is 4.28.

The relation of tools and sectors is shown in Figure 4.48. In order to be able to derive results, tools used in less than five articles are eliminated.

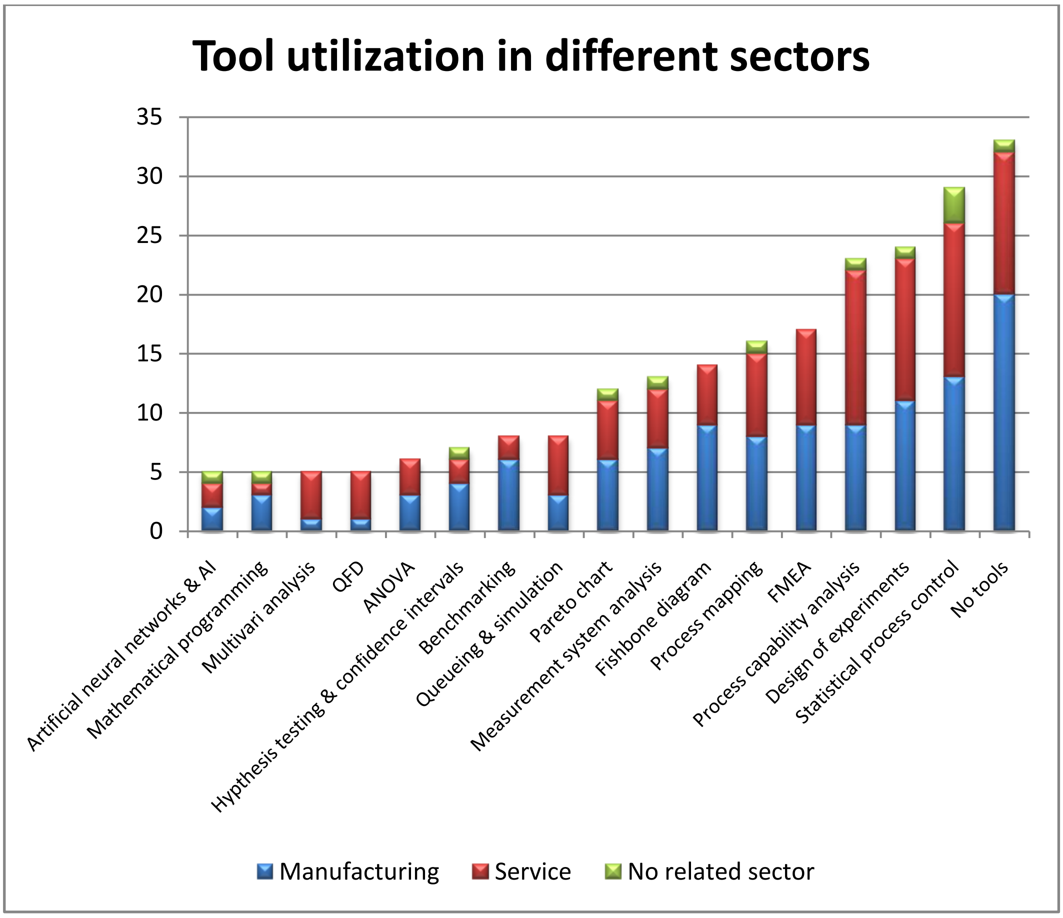


Figure 4.48 Tool utilization in different sectors (manufacturing – service)

The figure shows that most of the tools are distributed equally between sectors. Multivariate analysis and ANOVA are preferred more in service sector examples, where benchmarking and fishbone diagram are popular in manufacturing examples.

Figure 4.49 shows the relationship of the affiliation of the corresponding authors and tools used.

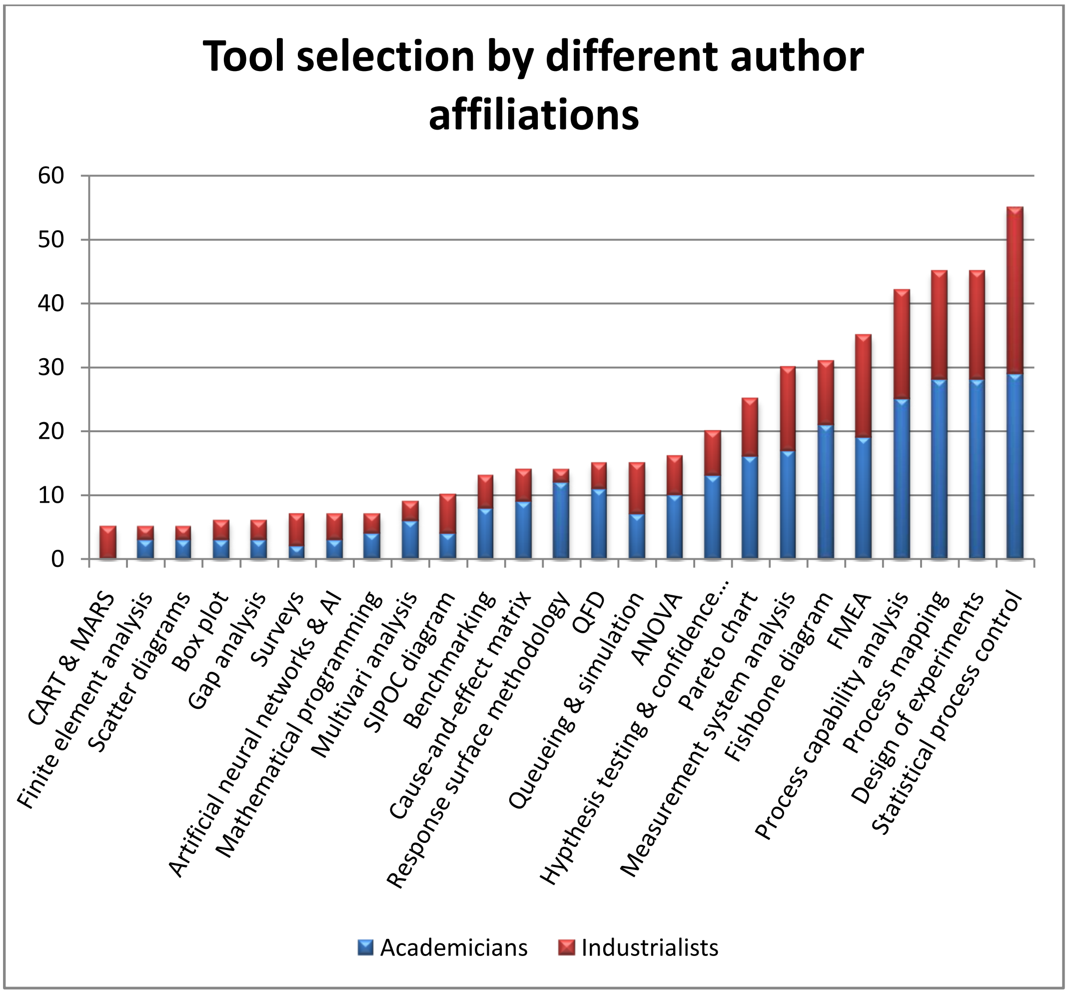


Figure 4.49 Tool selection by different author affiliations

In 54 articles by academicians, 296 tools were used, which makes 5.38 tools on average. This ratio is 3.96 tools per article (214/54) for authors from industry. On average, authors from academy use roughly 1 statistical tool more than the average number of tools used by authors from industry. CART/MARS, surveys, artificial neural networks & AI, SIPOC diagram, and queuing & simulation were the only tools used more commonly by industrialists. All other tools, especially DOE, process mapping, process capability analysis, fishbone diagram, and hypothesis testing & confidence intervals were preferred more by academicians.

This shows us that tools requiring statistical or industrial engineering background are used more by academicians. These tools could not penetrate into the six sigma practices of industrialists to the greatest extent.

To see the change in the use of the most common three tools, which are SPC, DOE and process mapping, within years, see Figure 4.50.

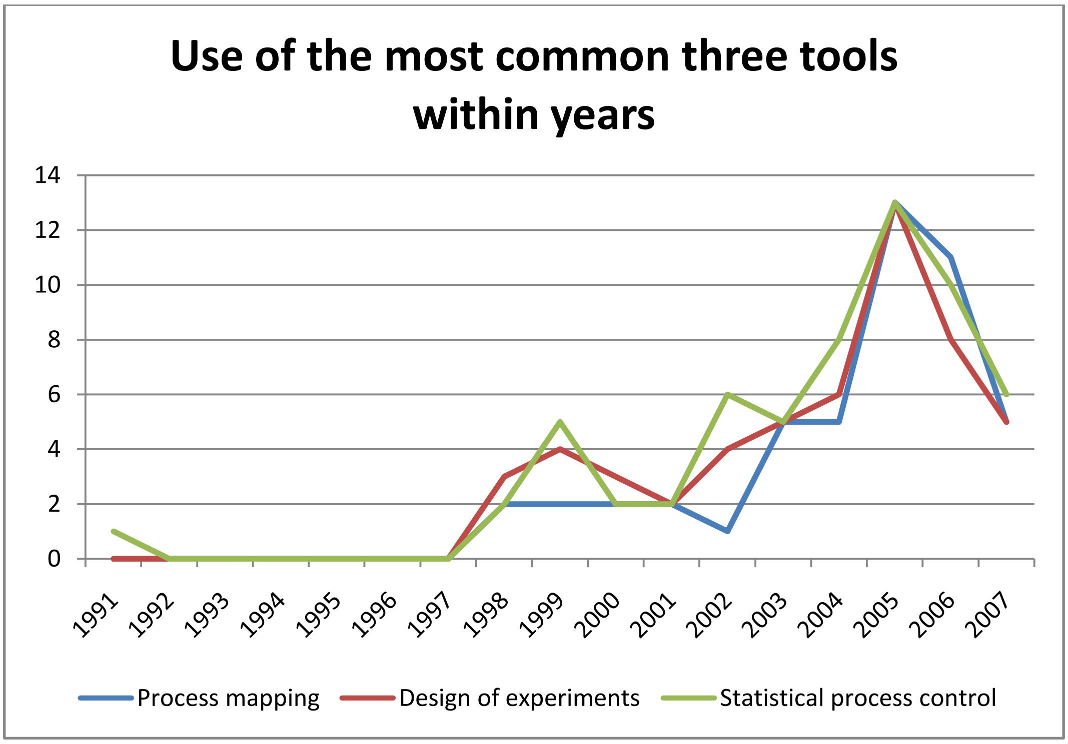


Figure 4.50 Number of mention of the most common three tools within years

The figure shows that a similar pattern among all three tools. All of them were almost never used before 1997. This period is followed by an increase trend with a peak point in 2005 for all three tools. Further analysis of the literature in the following years is going to reveal the meaning of the decrease in the last two years, 2006 and 2007. An interesting note is that, in 2006, more articles were published when compared to 2005. Therefore, the peak in 2005 and drop in 2006 are not attainable to the total number of articles published.

The analysis of tools till this point was a general analysis and did not include any details about the points in which step of six sigma methodology these tools were used or mentioned. Figure 4.51 provides an analysis of the number of tool used in different steps of DMAIC or DMADV methodologies. Please note that in the same article, a tool might be mentioned in more than one steps. In this case, the tool is counted more than once for that article.

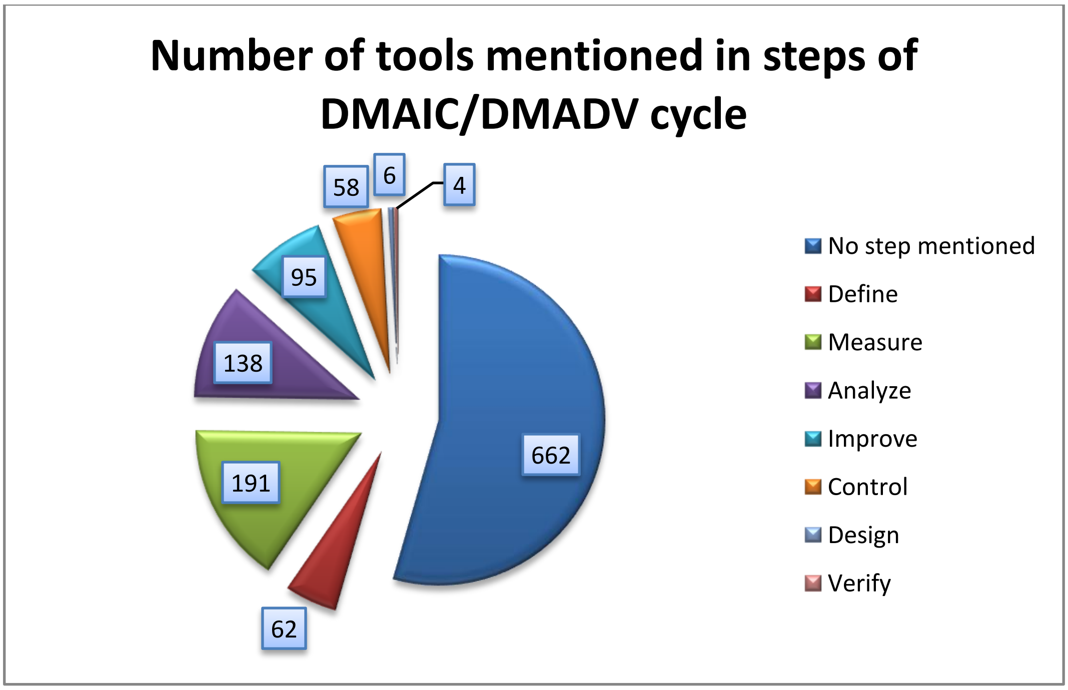


Figure 4.51 Number of tools mentioned in steps of DMAIC/DMADV cycle

The figure shows that measure and analyze steps are the steps in which a higher number of tools are used. This means that they are discussed deeper with more application examples. General focus of the studies is on these steps. The steps which are only present in DFSS methodology, i.e. design and verify, were almost never studied with tools. Only 5 tools were used for these steps. From this graph, the necessity of new tools in different parts of six sigma methodology can be derived.

Table 4.9 is given to see how many times the tools are used in each step.

Table 4.9 Tools and the phases in which they are used

Tool Name	No step mentioned	Define	Measure	Analyze	Improve	Control	Design	Verify
Statistical process control	40	0	7	2	2	17	0	1
Design of experiments	34	1	2	5	15	0	0	0
FMEA	26	2	6	7	1	2	0	0
Process capability analysis	23	1	15	4	4	5	0	0
Process mapping	23	10	12	5	1	1	0	0
Fishbone diagram	22	0	9	5	1	0	0	0
Pareto chart	17	3	7	4	1	0	0	0
Measurement system analysis	17	0	15	1	0	3	0	0
QFD	11	3	3	0	0	0	0	0
Hypothesis testing & CI	11	0	1	9	5	0	0	0
Benchmarking	10	1	3	3	0	0	0	0
Queueing & simulation	10	0	1	2	3	1	1	1
Response surface methodology	8	0	0	3	3	0	0	0
ANOVA	8	0	0	7	3	0	0	0
Surveys	7	0	0	0	0	0	0	0
Artificial neural networks & AI	7	0	0	0	1	0	0	0
Scatter diagrams	6	0	0	2	0	0	0	0
Multivari analysis	6	0	0	4	0	0	0	0
Cause-and-effect matrix	6	1	7	0	0	0	0	0
CART & MARS	4	0	0	0	0	0	1	0
Mathematical programming	4	0	0	1	2	0	0	0
SIPOC diagram	4	6	1	0	0	0	0	0
Fuzzy logic	3	0	0	0	1	0	0	0
Affinity diagrams	3	1	0	1	0	0	0	0
Finite element analysis	3	0	2	0	0	0	0	0
Box plot	3	0	2	0	2	0	0	0
TRIZ	2	0	0	0	0	0	0	0
DFM/DFA	2	0	0	0	0	0	0	0
Time series analysis	2	0	1	1	0	0	1	0
Sensitivity analysis	2	0	0	1	1	0	0	0
Gap analysis	2	1	1	2	0	0	0	0
FAST diagrams	1	0	0	0	0	0	0	0
Pugh matrix	1	0	0	0	0	0	0	0
Data mining	1	0	0	0	0	0	0	0
Contingency table analysis	1	0	0	0	0	0	0	0
Genetic algorithms	1	0	0	0	1	0	0	0
Fault tree analysis	0	1	0	0	0	0	0	0
Analytic hierarchy process	0	0	0	0	1	0	0	0
SWOT analysis	0	0	1	0	0	0	0	0
TOTAL	331	31	95	69	47	29	3	2

From the table, Figure 4.52 can be constructed to analyze the popularity of tools within steps visually.

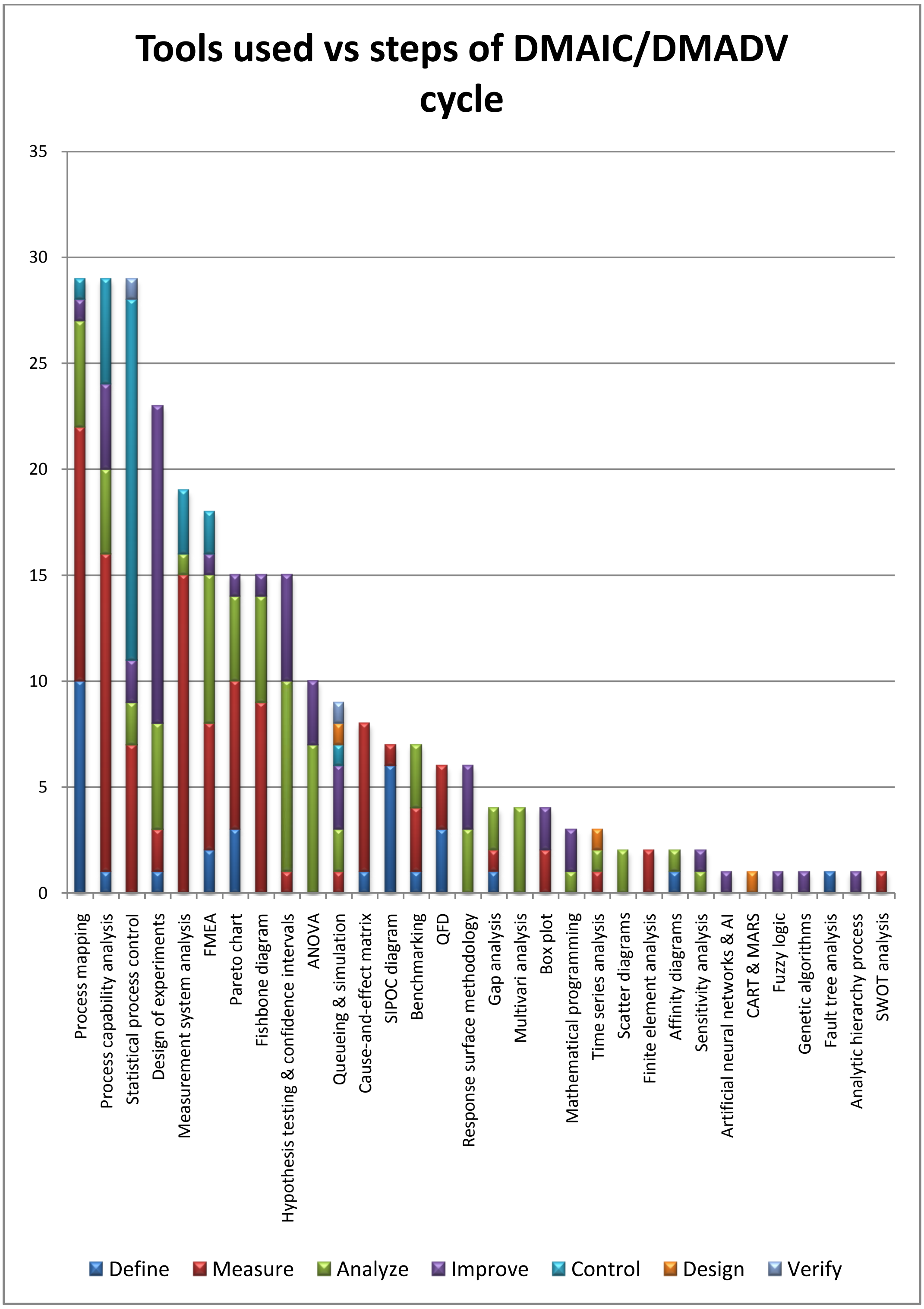


Figure 4.52 Tools preferred in different phases

The figure shows that certain tools are more related with certain steps. For example, SPC has a longer light blue bar, which reveals that it is more commonly used in control phase. This makes sense because after a six sigma study, a control mechanism is settled, which almost each time includes a SPC implementation. On the other hand, measurement system analysis has a longer red bar, which confirms it is used in measure phase. In six sigma practices, the measurement phase generally starts with a measurement system analysis to make sure that the measurements that are going to be the basis for all the work done, are consistent and reliable.

Figure 4.53 classifies the tools based on the steps in which they are used most frequently.

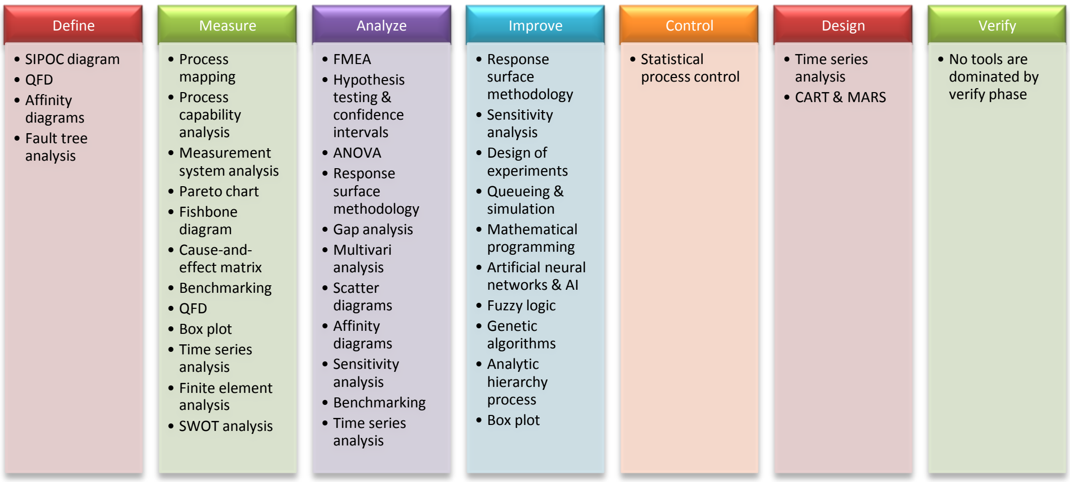


Figure 4.53 Steps in which every tool is used most

For the most popular five tools in each step, see Figure 4.54.

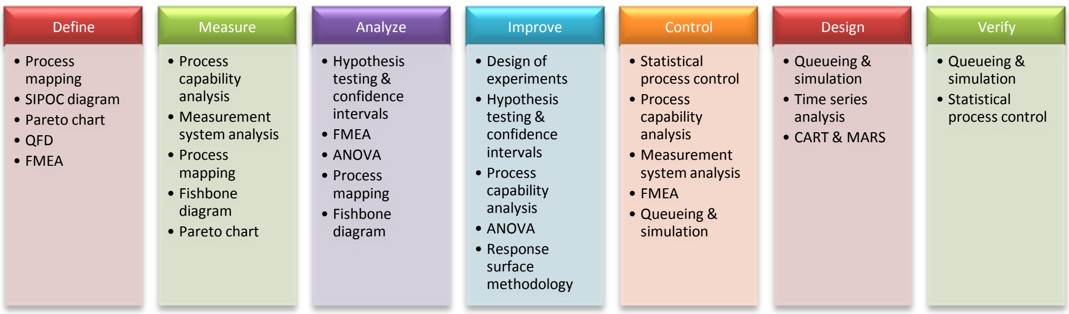


Figure 4.54 Most popular five tools in each step

4.19 Design for Six Sigma (DFSS)

DFSS methodology was introduced in Chapter 3. Since DFSS is relatively new when compared to six sigma, an analysis is made to see how many times DFSS is taken into consideration. These articles may be mainly about DFSS, or DFSS may be mentioned in any context in the articles. Figures 4.56 and 4.57 are available for the existence of DFSS in the literature.

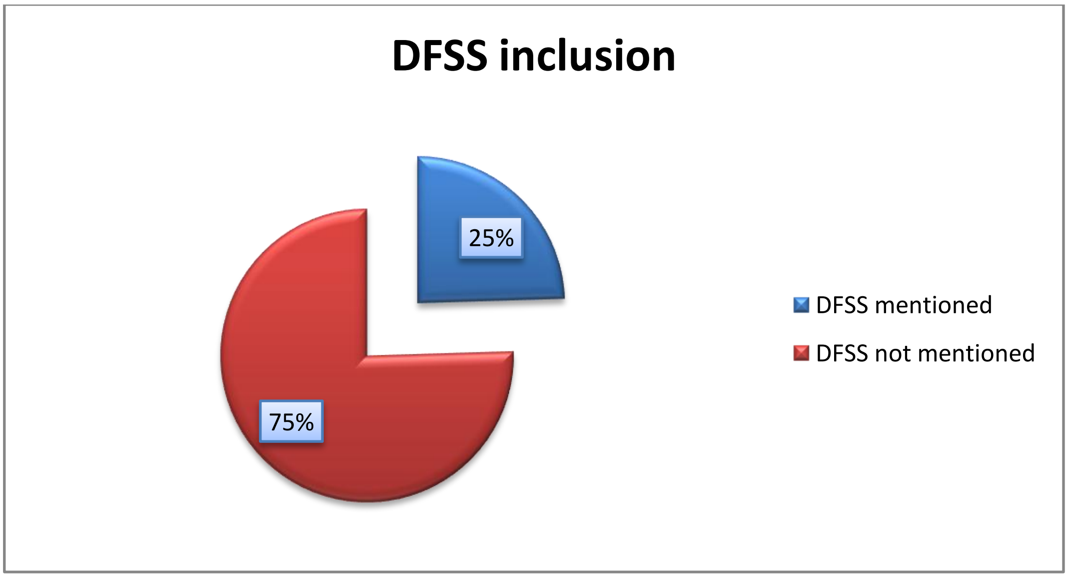


Figure 4.55 Percentage of articles that mentioned DFSS

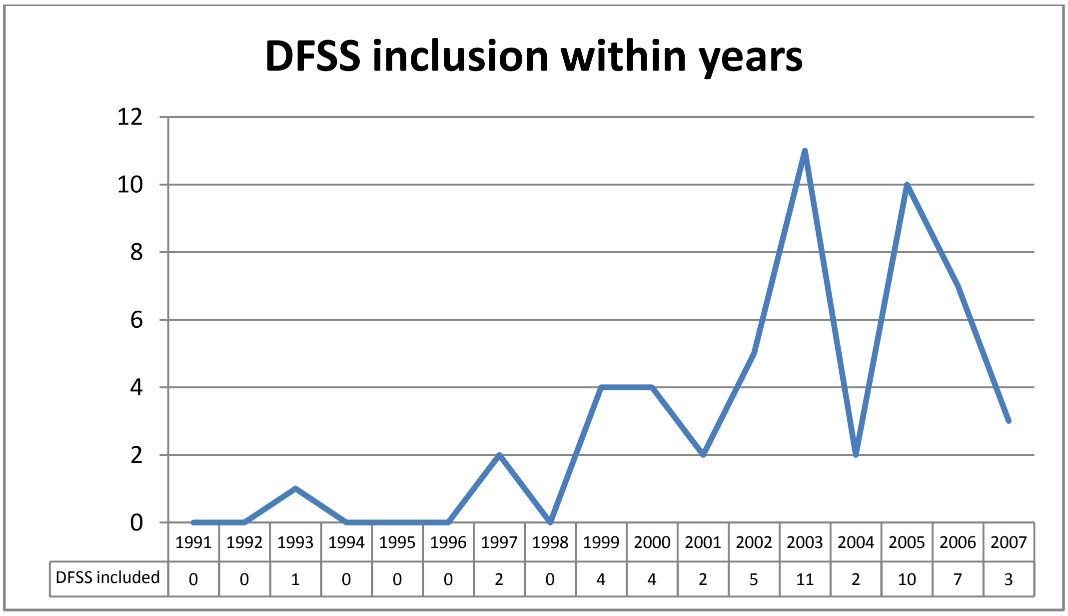


Figure 4.56 Number of articles that mentioned DFSS within years

The first graphic shows that 51 of all articles (25%) included a reference to DFSS. As it can be seen from the second figure, the first article was published in 1993 (Smith, 1993). After that, the literature on the issue started to grow beginning with the year 1997, without the presence of a visible pattern.

Figure 4.57 shows that one-fourth ratio of DFSS inclusion is applicable to the set of articles mainly about six sigma too.

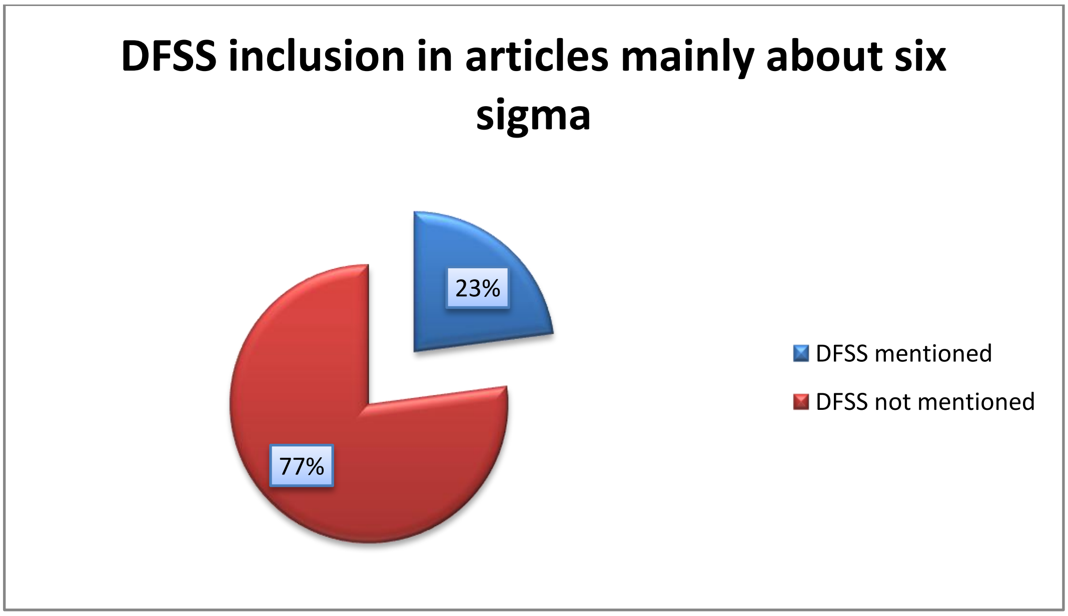


Figure 4.57 DFSS inclusion in articles mainly about six sigma

Figure 4.58 below displays a sectoral analysis of the 51 articles that referred to DFSS.

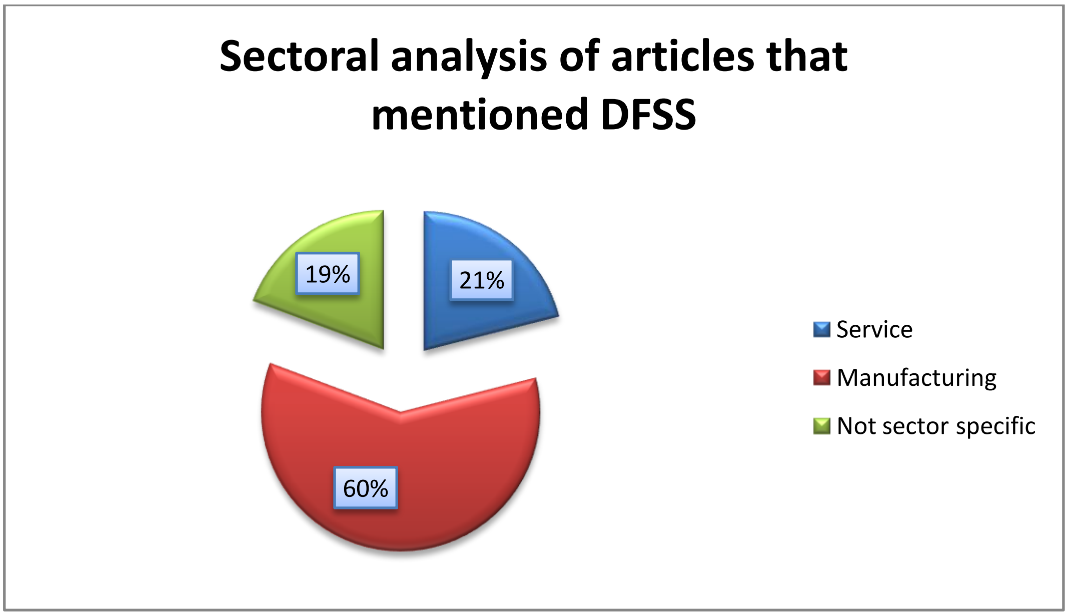


Figure 4.58 Sectoral analysis of articles that mentioned DFSS

As the figure suggests, and as it is expected, the main field of DFSS is manufacturing. The small slice of service sector suggests that design of service processes is starting to be studied, especially in healthcare (Frings & Grant, 2005), software (Harrold, 1999) and finance sectors (Patterson, Bonissone, & Pavese, 2005).

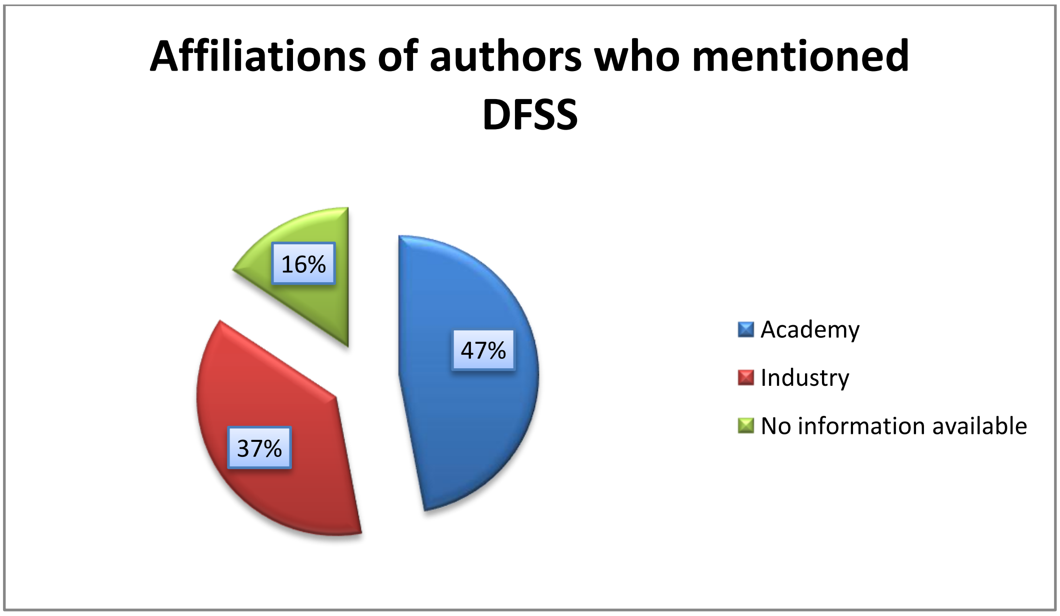


Figure 4.59 Percentage of the affiliation of the corresponding authors who mentioned DFSS

When the affiliations of the corresponding authors of these articles are analyzed, academicians are found to use/mention DFSS methodology more. This result rejects probable ideas suggesting that DFSS emerged as a heal for six sigma's inadequacy to address processes at their earlier design phases, and therefore as a result of necessity discovered during practice. DFSS is used by authors from academy at least as much as authors from industry.

For the types of articles that mentioned DFSS, Figure 4.60 is given.

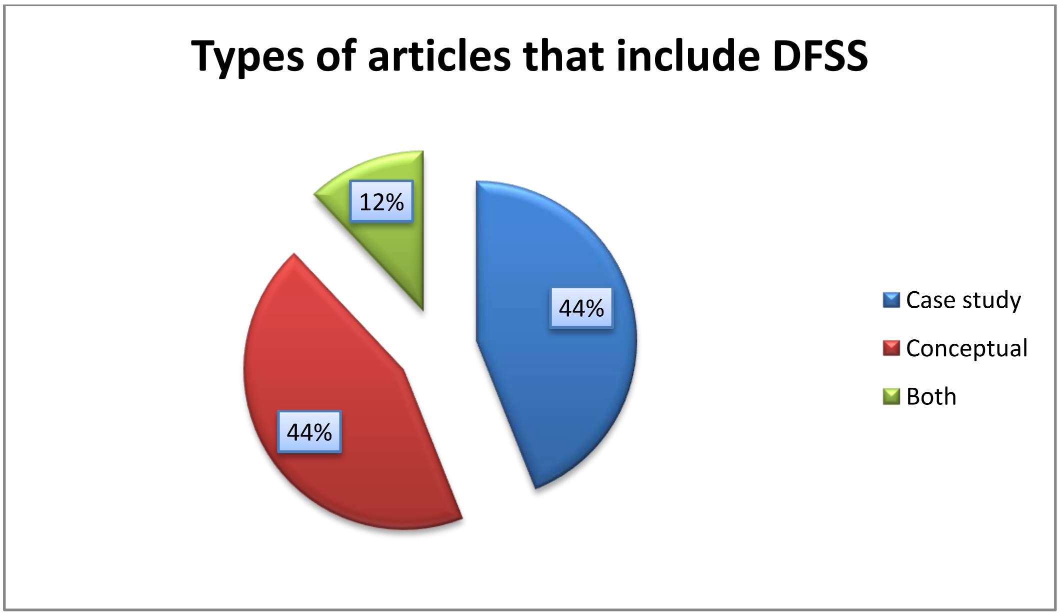


Figure 4.60 Percentage of the article types that mentioned DFSS

The articles that include at least one case study have a higher proportion of 56% against purely conceptual articles. Any significant difference between case studies and conceptual articles in mentioning six sigma is not present.

CHAPTER FIVE
DISCUSSION & CONCLUSION

In this literature review on six sigma, a history of quality was given firstly. The roots of quality concept and the developments in the world economic system were discussed. The Japanese quality movement and the emergence of six sigma were described. The history of quality in Turkey was also handled and beginning from the Ottoman Empire, the chronology of quality-related events was conveyed.

The following chapter provided an introduction to six sigma, its underlying theory, and methodology. Variation concept and the statistical meaning of six sigma were explained in that chapter.

In Chapter 4, the academic literature related with six sigma was reviewed. For this a SCI Expanded search for *six sigma* in title or subject/abstract parts of was conducted. A list of 245 articles, 208 of which were available full-text, was then reviewed and trends were identified in the scholarly literature. Special attention was paid to information about authors, article types, related sectors, definitions, success factors, critiques, challenges, and tools used in different phases of six sigma implementation.

In this chapter, promising future research areas will be suggested, some key findings of the literature survey will be highlighted by giving a brief summary of Chapter 4 and some discussions about the literature survey as a whole and six sigma methodology will be made.

5.1 Future Research Directions

In future works, the reasons of the decrease in number of articles in 2007 (and many decreasing figures shown in Section 3) can be analyzed. In this study, these figures could not be analyzed to a great extent, because it was probable that some journals' latest issues of 2007 had not been issued yet. Even if a negative trend existed in the end of the year, it was too early to draw conclusions. Thus, the replication of the literature review in the following years would be more helpful in revealing the situation of the six sigma literature in 2007.

The study could be enhanced by including the 37 articles of which full-text versions could not be reached. Although it is believed that an analysis including 85% of all articles in full-text and others in bibliographic records could give a good idea about the literature, it is not possible to draw conclusions with perfect certainty. Moreover, the analysis included a small amount of subjectivity, because the critics, challenges, future ideas, success factors, and tools were derived from the articles, and some even more subjective subjects were discussed like “being mainly about six sigma”. It is believed that the same study replicated by a different researcher would identify same trends and discover similar figures, however with slight differences due to human factor. The best way to interpret this review is not to focus on exact numbers or percentages, but to focus on general trends.

Other future studies may include a literature/practice review of six sigma in Turkey. Turkish industry has started adopting six sigma methodology and the concept is gaining popularity. The local issues about six sigma implementations in Turkey deserve an analysis.

Several articles published in applied statistics journals tried to redefine the role of statisticians after six sigma. No such work about the changes in the expectations from industrial engineers, or new roles emerged for them could be found. Industrial engineering profession, which holds a big role in six sigma, can be studied in future works.

5.2 Six Sigma Literature

With no time limits set in the literature survey, SCI Expanded research returned a set of articles spanning years between 1991 and 2007.

The review showed that one country dominated the six sigma literature: The US. As the section on history showed, six sigma was an American answer to the Japanese quality movement, which is in accordance with our finding. Antony (2007) expects more applications in Far East in the near future. However, it was interesting to note that only one Japanese corresponding author was found (Mizuyama, 2005).

As for the affiliations of the corresponding authors, there were slightly more authors from academy than those from industry. The academician presence in the literature exhibited an increasing trend, which is an evidence for the increasing interest in six sigma in the academia.

Articles in the list were most frequently published in journal about OR/MS. The high numbers of multidisciplinary engineering and management journals were also significant.

Of all 245 articles, 13 were cited more than 10 times, and only 4 of them exceeded 20 citations. It was also interesting to note that 66 of these 245 articles did not refer to any other articles. Indeed some articles published in "magazines" aimed at advertising for a statistical software, and it was quite hard to agree that certain articles possessed an academic value beyond their authors' personal ideas or experiences.

3 articles in 10 were identified as targeting a different subject than six sigma. Some analysis necessitating relevance to the subject for accurate data was conducted based on remaining articles, which were referred to as "articles mainly about six sigma".

58% of the articles included at least one case study. The number of conceptual articles has been decreasing gradually since 2000, identifying an escalating attention to six sigma in service sector. Manufacturing origins of six sigma did not limit the methodology and progress is made at various business functions, where so much hidden costs lie. The number of service-related articles, with studies about healthcare sector being vanguard, shows an increasing trend.

Partial agreement could be observed in tool usage, success factors, metrics, and other quality initiatives mentioned. On the other hand, definition, challenges, ideas about the future, and critiques varied extensively among authors. Definitions provided in the articles differed considerably. Therefore a classification for the definitions was made and those the number of articles that provided definitions from a statistical perspective constituted the dominant side against those with a management perspective. 64 articles not mentioning any definition is believed to be a result of the increased general awareness. As more people know about six sigma, the necessity of precise definitions fades.

DMAIC cycle was described in two-thirds of the articles, while it is shockingly discovered that 22 case studies did not say a single word on DMAIC.

Six sigma's relations with other quality initiatives were studied frequently. Lean and six sigma integration was significantly argued. However, the decision making process of whether to adopt six sigma or another initiative could be analyzed in more detail. Even though six sigma describes itself as an umbrella just like every new management system does (Pannell, 2006), the availability analysis should be made in every new practice.

Nearly half of the articles gave tips about successful implementations (defined as success factors). The most commonly used three success factors were "management commitment", "training", and "having clear performance metrics, integration with existing business initiatives".

As the critiques about six sigma were analyzed, it was seen that the methodology was usually alleged to be "a management fad" or "the latest flavor of the month". Critiques about the lack of invention/innovation orientedness were noted.

The most common challenge faced during six sigma implementations was budget constraints. However, “resistance to culture change” is believed to be a more serious challenge which implicitly exists and causes many other challenges.

The performance of six sigma programs was defined either in the monetary terms or reduction in variation and cycle time. Other metrics were rarely used.

Every single tool used in the articles was listed and the most common tools turned out to be SPC and DOE, which are used as standalone quality initiatives in some firms. However, the utilization of tools within six sigma context and methodology added significant value to them. Most of the tools were used in Measure and Analyze phases of DMAIC. Future works may put more focus on other steps. The most popular five tools in each step was identified and tabulated.

Lastly, the mention of DFSS methodology in the literature was analyzed. 1 in 4 articles referred to DFSS.

At the end of the literature review, it would not be an overstatement to say that high popularity of six sigma has a negative impact on the academic character of the literature. Articles used as an advertising tool, articles with no citations (given or received), case studies without DMAIC methodology being mentioned, and even case studies without a word from any single tool were not expected in this set of articles, the academic quality of which is assured by SCI Expanded. As the commercial part of six sigma outpaced the scientific part, the academy lagged behind in its understanding of six sigma.

5.3 Discussions

In the light of the articles analyzed during the literature survey, the following points are believed to be important in the future of six sigma:

- Many authors complain about too much slogans, advertising, and buzz words in six sigma, which are not supported by profound technical knowledge. Linderman et al. (2003) say “six sigma is a phenomenon that is gaining wide acceptance in industry, but lacks a theoretical underpinning and a basis for research other than “best practice” studies”.

- In the near future, researchers and practitioners can be expected to introduce new tools to six sigma methodology concerning design (Hahn & Hoerl, 1998), or idea generation (Harrold, 1999). However, criticizing six sigma about not introducing new tools (Horst, 2004; Mullin, 2003) is believed to be unfair. Hahn and his colleagues (1999) state very correctly that “while the tools are not new, six sigma approach adds considerable value to the use of existing tools”. Moreover, Arvidsson, Gremyr, and Johansson (2003) noted after a survey that companies that involved in a six sigma program used statistical methods to a greater extent when compared to the companies that were not.

- DPMO values are used in sigma calculations but this is based on the assumption that all defects have the same importance. New approaches assigning different importance weights to different defects might contribute to the real-life success of six sigma.

- Success stories should be read once more considering Hawthorne effect, and advertorial “dollar figures” should not be overemphasized. *Self-reported profits* (Brady & Allen, 2006) should be doubted and quantitative metrics of reduction in variation should be utilized more. This would be helpful in the implementation of six sigma initiatives in public sectors, in which the main aim is not profit. Although six sigma is driven by tangible benefits as opposed to the quality idealism of TQM (Kumar et al., 2006), monetary metrics do not make any “academic” sense because they are nothing but a function of changes in other metrics plus prices of certain resources.

- In the forthcoming period, small and medium sized enterprises are expected to use six sigma programs more (Hahn, 2005). Harry and Crawford's (2004) proposal of cheaper-to-train "white belts" and cheaper web based training programs are supportive in that. Advances in information technologies, robotics, network solutions and internet infrastructure (Hsieh et al., 2007) are expected to bring more cost-effective and more collaborative six sigma initiatives. Further use of artificial neural networks, fuzzy logic, and genetic algorithms are also expected (Tang et al., 2007).

- Perfection in processes is desirable, however, the following assumptions presented by Nave (2002) should also be subject to debate:
  - "The design of product or service is essentially correct,
  - The design of product or service is the most economical,
  - Customer needs are satisfied with that design,
  - The current product configuration fulfills the functional requirements of the market and customer,
  - The management structure supports and nourishes change."

  Motorola, the owner of "six sigma" registered trademark, is the company who introduced Iridium satellite phones, which received virtually no market demand and disastrously cancelled the "probably perfect and six sigma level" production process. Companies should ask if they are making the right processes perfect.

- The new pace of business is challenging six sigma: Shorter lead times, shorter product introduction times, and new trends like customization (Goh, 2002) e-business and e-commerce (Doble, 2005) are demanding faster six sigma implementations, lean and six sigma integration, and more DFSS utilization. Pearson (2001) asks how to justify six sigma improvement projects that lasted 4-6 months when its products changed every 2 months.

- Because the perception of six sigma is inconsistent, six sigma concepts do not mean the same thing in every organization. Engineers declaring themselves as “black belts” or “green belts” have no grounds indeed. In six sigma, “there are no standardized criteria for certification, as there are with accountants, lawyers and engineers.” (Hoerl, 2001) “Each organization implementing six sigma is currently being left to its own method of certifying.” (Munro, 2000) This unstructured certification phenomena has to be refined within the industry.

- Finally, the human side of change should be addressed more (Shoaf, Genaidy, Karwowski, & Huang, 2004). The effects of six sigma on labor force should be analyzed. Uncomfortable workforce should be convinced by using the gains of six sigma in order to provide a better life for them, not for improving productivity and laying off more workers.

If six sigma will prove itself being a real standard, it will be discussed more, studied academically more, its perception will thus be homogenized as other quality systems like TQM or ISO; otherwise as it will become an advertising slogan in the weekly magazines, the positive conviction towards six sigma will disappear in the course of time.

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APPENDIX I

Accreditation and Quality Assurance	Journal of Aircraft
Advances in Fracture and Strength, Pts 1- 4	Journal of Applied Statistics
Advances in Polymer Technology	Journal of Clinical Ligand Assay
Aircraft Engineering and Aerospace Technology	Journal of Computer Information Systems
American Journal of Clinical Pathology	Journal of Construction Engineering and Management-ASCE
American Journal of Medical Quality	Journal of Electronic Packaging
American Journal of Roentgenology	Journal of Engineering Design
American Statistician	Journal of Evaluation in Clinical Practice
Anesthesia and Analgesia	Journal of General Internal Medicine
Angewandte Makromolekulare Chemie	Journal of Hazardous Materials
Annual Reliability and Maintainability Symposium, 2002 Proceedings	Journal of Management in Engineering
Annual Reliability and Maintainability Symposium, 2003 Proceedings	Journal of Manufacturing Science and Engineering-Transactions of the ASME
Annual Reliability and Maintainability Symposium, 2005 Proceedings	Journal of Materials Processing Technology
Applied Catalysis A-General	Journal of Mechanical Design
Applied Soft Computing	Journal of Nursing Administration
Archives of Pathology & Laboratory Medicine	Journal of Operations Management
Assembly Automation	Journal of Optimization Theory and Applications
Aviation Week & Space Technology	Journal of Pharmaceutical and Biomedical Analysis
Chemical & Engineering News	Journal of Propulsion and Power
Chemical Engineering	Journal of Quality Technology
Chemical Engineering Communications	Journal of Systems and Software
Chemical Engineering Progress	Journal of the American College of Surgeons
Chemical Processing	Journal of the IES
Chemical Week	Journal of the Operational Research Society
Chimica Oggi-Chemistry Today	Journal of the Society For Information Display
Clinical Chemistry	Journal of Water Supply Research and Technology-Aqua

Clinics in Laboratory Medicine	Kautschuk Gummi Kunststoffe
Computers in Industry	Labmedicine
Concurrent Engineering-Research and Applications	Laboratory Medicine
Control Engineering	Lecture Notes in Computer Science
Cots-Based Software Systems, Proceedings	Management Science
Euro Ceramics VIII, Pts 1-3	Manufacturing Engineering
Filtration & Separation	Mechanical Engineering
Genetic Engineering News	Medical Physics
Ground Water Monitoring and Remediation	Microelectronics Reliability
Hewlett-Packard Journal	Milbank Quarterly
Human Factors and Ergonomics in Manufacturing	Naval Engineers Journal
Hydrocarbon Processing	Pharmazeutische Industrie
IEEE Circuits and Devices Magazine	Physica C
IEEE Instrumentation & Measurement Magazine	Polymer Composites
IEEE Software	Polymer-Plastics Technology and Engineering
IEEE Spectrum	Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture
IEEE Transactions on Automation Science and Engineering	Proceedings of the Institution of Mechanical Engineers Part D-Journal of Automobile Engineering
IEEE Transactions on Electronics Packaging Manufacturing	Process Safety Progress
IEEE Transactions on Neural Networks	Production Planning & Control
IEEE Transactions on Semiconductor Manufacturing	Professional Engineering
IIE Solutions	Program-Electronic Library and Information Systems
Indian Journal of Chemistry Section A-Inorganic Bio-Inorganic Physical Theoretical & Analytical Chemistry	Quality & Quantity
Industrial & Engineering Chemistry Research	Quality and Reliability Engineering International
Industrial Engineer	Quality Progress
Industrial Management & Data Systems	R&D Magazine
Informacije Midem-Journal of Microelectronics Electronic Components and Materials	Research-Technology Management
Information and Software Technology	Simulation-Transactions of the Society For Modeling and Simulation International

Informs Journal on Computing	Software Quality Journal
Ingenieria Quimica	Soldering & Surface Mount Technology
Intelligent Tutoring Systems	Solid State Technology
Interfaces	Sound and Vibration
International Journal of Advanced Manufacturing Technology	Space Technology-Industrial and Commercial Applications
International Journal of Automotive Technology	SPE Production & Facilities
International Journal of Cardiovascular Imaging	Strojniski Vestnik-Journal of Mechanical Engineering
International Journal of Engineering Education	Structural and Multidisciplinary Optimization
International Journal of Materials & Product Technology	Structural Safety
International Journal of Production Research	Technometrics
International Journal of Std & Aids	Technovation
International Journal of Technology Management	Therapeutic Apheresis
JCT Coatingstech	Ultra Clean Processing Of Silicon Surfaces Vii

APPENDIX II

Part I – Bibliographic Information

No	Authors	Year	Title	Journal Name	Subject Categories	Number of References	Times Cited	Volume	No	Pages	Country	Affiliation
1	Harrold, D.	1999	Designing for six sigma capability	Control Engineering	Automation & Control Systems; Engineering, Electrical & Electronic; Instruments & Instrumentation	0	3	46	1	62-67	-	-
2	Buggie, F.D.	2000	Beyond 'six sigma'	Journal of Management in Engineering	Engineering, Industrial; Engineering, Civil	0	2	16	4	28-31	USA	Industry
3	Walters, L.	2005	Six sigma: is it really different?	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	0	2	21	3	221-224	USA	Industry
4	Velocci, A.L.	2002	Full potential of six sigma eludes most companies	Aviation Week & Space Technology	Engineering, Aerospace	0	1	157	14	56-60	-	-
5	Kandebo, S.W.	1999	Lean, six sigma yield dividends for C-130J	Aviation Week & Space Technology	Engineering, Aerospace	0	1	151	2	59-61	-	-
6	Velocci, A.L.	1998	Pursuit of six sigma emerges as industry trend	Aviation Week & Space Technology	Engineering, Aerospace	0	1	149	20	52-56	-	-
7	Velocci, A.L.	1998	High hopes riding on six sigma at Raytheon	Aviation Week & Space Technology	Engineering, Aerospace	0	1	149	20	59-59	-	-
8	Velocci, A.L.	1998	Six sigma takes a back seat to 'lean electronics' at Rockwell	Aviation Week & Space Technology	Engineering, Aerospace	0	1	149	20	60-60	-	-
9	Harrold, D.	1999	Optimize existing processes to achieve six sigma capability	Control Engineering	Automation & Control Systems; Engineering, Electrical & Electronic; Instruments & Instrumentation	0	1	46	3	87-90	-	-
10	Bartos, F.J.	1999	Six Sigma for complex systems	Control Engineering	Automation & Control Systems; Engineering, Electrical & Electronic; Instruments & Instrumentation	0	1	46	3	90-90	-	-
11	Henretta, K.; Walker, J.; Bellafiore, L.	2003	Applying "six sigma" to chromatography - Tutorial: Cutting costs through process improvements	Genetic Engineering News	Biotechnology & Applied Microbiology; Genetics & Heredity	0	1	23	1	54-56	USA	Industry
12	Ackermann, C.S.; Fabia, J.M.	1993	Monitoring Supplier Quality At PPM Levels	IEEE Transactions on Semiconductor Manufacturing	Engineering, Manufacturing; Engineering, Electrical & Electronic; Physics, Applied; Physics, Condensed Matter	0	1	6	2	189-195	USA	Industry
13	Basu, R.	2001	Six sigma to fit sigma	IIE Solutions	Engineering, Industrial	0	1	33	7	28-33	-	-
14	Cooper, D.W.; Babcock, J.V.; Dipietro, F.	1992	Application of 6 sigma-statistical quality-control to monitoring the deposition of contaminating particles	Journal of the IES	Engineering, Environmental; Environmental Sciences; Instruments & Instrumentation	0	1	35	5	27-32	USA	Industry
15	Woeste, S.	2006	Six sigma, lean management, and hand-held computers: decrease errors in clinical tasks	Labmedicine	Medical Laboratory Technology	0	1	37	5	269-271	-	-
16	Connor, G.	2003	Benefiting from six sigma	Manufacturing Engineering	Engineering, Manufacturing	0	1	130	2	53-59	-	-
17	Olexa, R.	2003	Driving quality with six sigma	Manufacturing Engineering	Engineering, Manufacturing	0	1	130	2	61-66	-	-
18	Howell, D.	2000	The power of six	Professional Engineering	Engineering, Mechanical	0	1	13	14	34-35	-	-
19	Cooper, N.P.; Noonan, P.	2003	Do teams and six sigma go together?	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	0	1	36	6	25-28	USA	Academy
20	Harry, M.J.	2000	Abatement of business risk is key to six sigma	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations	0	1	33	7	72-75	USA	Industry

No	Authors	Year	Title	Journal Name	Subject Categories	Number of References	Times Cited	Volume	No	Pages	Country	Affiliation
					Research & Management Science							
21	Harry, M.J.	2000	Six sigma focuses on improvement rates	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	0	1	33	6	76-80	USA	Industry
22	Breyfogle, F.	2003	Six sigma methods to ensure organizations' health	R&D Magazine	Engineering, Industrial; Multidisciplinary Sciences	0	1	45	4	28-29	USA	Industry
23	Connolly, M.	2003	Six sigma deployment at DuPont	R&D Magazine	Engineering, Industrial; Multidisciplinary Sciences	0	1	45	4	29-29	USA	Industry
24	Fitzpatrick, D.; Looney, M.	2003	A roadmap to greater efficiency in aerospace operations through the application of six sigma and lean manufacturing techniques	Aircraft Engineering and Aerospace Technology	Engineering, Aerospace	0	0	75	3	274-277	-	-
25	Kapur, K.C.	2002	The future of reliability engineering as a profession	Annual Reliability and Maintainability Symposium, 2002 Proceedings	Engineering, Multidisciplinary	0	0			434-435	USA	Academy
26	Lee-Mortimer, A.	2006	Six sigma: effective handling of deep rooted quality problems	Assembly Automation	Automation & Control Systems; Engineering, Manufacturing	0	0	26	3	200-204	-	-
27	Lee-Mortimer, A.	2006	Six sigma: a vital improvement approach when applied to the right problems, in the right environment	Assembly Automation	Automation & Control Systems; Engineering, Manufacturing	0	0	26	1	10-17	-	-
28	Anonymous	2002	The ABCs of six sigma	Aviation Week & Space Technology	Engineering, Aerospace	0	0	157	14	56-57	-	-
29	Velocci, A.L.	2000	Raytheon six sigma meets initial target	Aviation Week & Space Technology	Engineering, Aerospace	0	0	152	13	59-59	-	-
30	Anonymous	1998	Success with six sigma often an elusive goal	Aviation Week & Space Technology	Engineering, Aerospace	0	0	149	20	53-53	-	-
31	Mullin, R.	2003	Eternal values via six sigma	Chemical & Engineering News	Chemistry, Multidisciplinary; Engineering, Chemical	0	0	81	1	19-19	-	-
32	Mccoy, M.	1999	Six sigma gaining as improvement method	Chemical & Engineering News	Chemistry, Multidisciplinary; Engineering, Chemical	0	0	77	45	11-12	-	-
33	Perlmutter, B.	2005	A six sigma approach to evaluating vacuum filtration technologies	Chemical Engineering Progress	Engineering, Chemical	0	0	101	8	42-47	USA	Industry
34	Anonymous	2003	Statistical software helps Dow reach six sigma goals - standardizing has simplified training and optimization efforts	Chemical Processing	Engineering, Chemical	0	0	66	9	23-24	-	-
35	Walters, L.	2000	Getting more than statistics with six sigma	Chemical Processing	Engineering, Chemical	0	0	63	5	34-39	USA	Industry
36	Walsh, K.; Fuller, J.; Wood, A.; Moore, S.K.; Schmitt, B.	2000	Six sigma - marshaling an attack on costs	Chemical Week	Engineering, Chemical	0	0	162	9	25-27	-	-
37	Crom, S.	2006	Right first time in pharmaceuticals: six sigma for continuous and breakthrough improvement	Chimica Oggi-Chemistry Today	Biotechnology & Applied Microbiology; Chemistry, Multidisciplinary	0	0	24	3	20-21	-	-
38	Manual, D.	2006	Six sigma methodology: reducing defects in business processes	Filtration & Separation	Engineering, Chemical	0	0	43	1	34-36	-	-
39	Depalma, A.	2006	Lean and six sigma approaches taking hold	Genetic Engineering News	Biotechnology & Applied Microbiology; Genetics & Heredity	0	0	26	7	1-4	-	-
40	French, C.M.; Duplancic, N.	2006	Application of six sigma methods for improving the analytical data management process in the environmental industry	Ground Water Monitoring and Remediation	Water Resources	0	0	26	2	58-61	USA	Industry
41	Gollomp, B.	2005	From zero defects to six-sigma - more than paper to electronic data	IEEE Instrumentation & Measurement Magazine	Engineering, Electrical & Electronic; Instruments & Instrumentation	0	0	8	2	70-71	-	-

No	Authors	Year	Title	Journal Name	Subject Categories	Number of References	Times Cited	Volume	No	Pages	Country	Affiliation
42	Nash, M.; Poling, S.R.; Ward, S.	2006	Six sigma speed - faster results come from a lean culture	Industrial Engineer	Engineering, Industrial	0	0	38	11	40-44	-	-
43	Pannell, A.	2006	Happy together - solid lean principles are at the heart of every successful six sigma program	Industrial Engineer	Engineering, Industrial	0	0	38	3	46-49	-	-
44	Elliott, G.	2003	The race to six sigma	Industrial Engineer	Engineering, Industrial	0	0	35	10	30-34	-	-
45	Zorko, R.	2006	About metrology from entrepreneurial microenvironment point of view	Informacije Midem-Journal of Microelectronics Electronic Components and Materials	Engineering, Electrical & Electronic; Materials Science, Multidisciplinary	0	0	36	2	110-115	Slovenia	Industry
46	Denizel, M.; Ekind, U.; Ozyurt, G.; Turhan, D.	2007	Ford-Otosan optimizes its stocks using a six-sigma framework	Interfaces	Management; Operations Research & Management Science	0	0	37	2	97-107	Turkey	Academy
47	Antony, J.	2007	Six sigma: a strategy for supporting innovation in pursuit of business excellence	International Journal of Technology Management	Engineering, Multidisciplinary; Management; Operations Research & Management Science	0	0	37	1/2	8-12	Scotland	Academy
48	Challener, C.	2004	Six sigma quality efforts have measurable impact	JCT Coatingstech	Chemistry, Applied; Materials Science, Coatings & Films	0	0	1	2	24-27	-	-
49	Miles, E.N.	2006	Improvement in the incident reporting and investigation procedures using process excellence (DMAI(2)C) methodology	Journal of Hazardous Materials	Engineering, Environmental; Engineering, Civil; Environmental Sciences	0	0	130	1/2	169-181	USA	Industry
50	Coker, S.; Glick, B.; Green, L.; Vonmayrhauser, A.	1992	Corporate software engineering-education for 6-sigma - course development and assessment of success	Lecture Notes in Computer Science	Computer Science, Theory & Methods	0	0	640		360-379	USA	Industry
51	Horst, R.L.	2004	Measuring and achieving six-sigma performance	Manufacturing Engineering	Engineering, Manufacturing	0	0	133	1	117-121	USA	Industry
52	Olexa, R.	2003	Fly high with six sigma quality	Manufacturing Engineering	Engineering, Manufacturing	0	0	130	2	69-73	-	-
53	Harry, M.J.; Crawford, J.D.	2004	Six sigma for the little guy	Mechanical Engineering	Engineering, Mechanical	0	0	126	11	8-10	USA	Industry
54	Ung, S.T.; Bonsall, S.; Williams, V.; Wall, A.; Wang, J.	2007	The application of the six sigma concept to port security process quality control	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	0	0	23	5	631-639	England	Academy
55	Anonymous	2000	GE uses six sigma process to develop education services	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	0	0	33	9	28-29	-	-
56	Boiler, C.	2005	How to maximise results for six sigma	R&D Magazine	Engineering, Industrial; Multidisciplinary Sciences	0	0	47	7	25-25	-	-
57	Boiler, C.	2004	How to maximize results for six sigma	R&D Magazine	Engineering, Industrial; Multidisciplinary Sciences	0	0	46	7	22-22	-	-
58	Joyce, L.	2004	Six sigma "add-ons" help companies make the leap	R&D Magazine	Engineering, Industrial; Multidisciplinary Sciences	0	0	46	1	36-38	-	-
59	Leong, C.Y.; Lim, W.B.; Cady, W.A.; Mustapha, N.A.; Lai, K.K.	2005	Effective polymer removal: process window-process uniformity-extended chemical bath-life	Ultra Clean Processing of Silicon Surfaces VII	Materials Science, Multidisciplinary; Physics, Applied; Physics, Condensed Matter	0	0	103-104		385-388	Singapore	Industry
60	Harry, M.J.	1998	Six sigma: a breakthrough strategy for profitability	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	1	18	31	5	60-64	USA	Industry
61	Smith, B.	2003	Lean and six sigma - A one-two punch	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	1	4	36	4	37-41	USA	Industry
62	Trivedi, Y.B.	2002	Applying six sigma	Chemical Engineering Progress	Engineering, Chemical	2	1	98	7	76-81	USA	Industry
63	Antony, J.	2007	Is six sigma a management fad or fact?	Assembly Automation	Automation & Control Systems; Engineering, Manufacturing	2	0	27	1	17-19	Scotland	Academy

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64	South, S.E.	2005	Achieving breakthrough improvements with the application of lean six sigma tools and principles within process excellence	Laboratory Medicine	Medical Laboratory Technology	2	0	36	4	240-242	USA	Industry
65	Neuscheler-Fritsch, D.; Norris, R.	2001	Capturing financial benefits from six sigma - five lessons learned will resonate with top management	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	2	0	34	5	39-44	USA	Industry
66	Adams, R.; Warner, P.; Hubbard, B.; Goulding, T.	2004	Decreasing turnaround time between general surgery cases - a six sigma initiative	Journal of Nursing Administration	Nursing	3	5	34	3	140-148	USA	Industry
67	Leffew, K.W.; Yerrapragada, S.S.; Deshpande, P.B.	2001	6 sigma and solid-state polymerization	Chemical Engineering Communications	Engineering, Chemical	3	3	188		109-114	USA	Academy
68	Bossert, J.	2003	Lean and six sigma - synergy made in heaven	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	3	3	36	7	31-32	USA	Industry
69	Stotsky, A.A.	2007	Statistical engine misfire detection	Proceedings of the Institution of Mechanical Engineers Part D-Journal of Automobile Engineering	Engineering, Mechanical; Transportation Science & Technology	3	1	221	D5	641-649	Sweeden	Industry
70	Gabriele, Q.A.S.; Padula, Q.F.; Genta, Q.K.	2007	Six sigma applied to industry	Ingenieria Quimica	Engineering, Chemical	3	0		31	16-21	-	-
71	Mccollough, G.T.; Rankin, C.M.; Weiner, M.L.	2006	Roll-to-roll manufacturing considerations for flexible, cholesteric liquid-crystal display (Ch- LCD) media	Journal of the Society For Information Display	Engineering, Electrical & Electronic; Materials Science, Multidisciplinary; Optics; Physics, Applied	3	0	14	1	25-30	USA	Industry
72	Herasuta, M.	2007	A "lean" laboratory	Labmedicine	Medical Laboratory Technology	3	0	38	3	143-144	USA	Academy
73	Urbanik, S.A.	2004	Evaluating relief valve reliability when extending the test and maintenance interval	Process Safety Progress	Engineering, Chemical	3	0	23	3	191-196	USA	Industry
74	Hoerl, R.W.	1998	Six sigma and the future of the quality profession	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	4	10	31	6	35-42	USA	Industry
75	Face, D.W.; Small, R.J.; Warrington, M.S.; Pellicone, F.M.; Martin, P.J.	2001	Large area YBa2Cu3O7 and Tl2Ba2CaCU2O8 thin films for microwave and electronic applications	Physica C	Physics, Applied	4	5	357		1488-1494	USA	Industry
76	Chan, A.L.F.	2004	Use of six sigma to improve pharmacist dispensing errors at an outpatient clinic	American Journal of Medical Quality	Health Care Sciences & Services	4	2	19	3	128-131	Taiwan	Industry
77	Treichler, D.; Carmichael, R.; Kusamanoff, A.; Lewis, J.; Berthiez, G.	2002	Design for six sigma: 15 lessons learned - Leading corporations find out how to avoid pitfalls	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	4	2	35	1	33-42	USA	Industry
78	Erginel, N.; Dogan, B.; Ay, N.	2004	The statistical analysis of coloring problems faced in ceramic floor tile industry	Euro Ceramics VIII, Pts 1-3	Materials Science, Ceramics; Materials Science, Composites	4	1	264-268		1693-1696	Turkey	Academy
79	Ahmed-Jushuf, İ.; Griffiths, V.	2007	Identifying hidden capacity through modernization of genitourinary medicine services	International Journal of Std & Aids	Immunology; Infectious Diseases	4	1	18	5	297-298	England	Academy
80	Ahmed-Jushuf, İ.; Griffiths, V.	2007	Reducing follow-ups: an opportunity to increase the capacity of genitourinary medicine services across the UK	International Journal of Std & Aids	Immunology; Infectious Diseases	4	1	18	5	305-307	England	Academy
81	Gross, J.M.	2001	A road map to six sigma quality	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	4	1	34	11	24-29	-	-
82	Kendall, J.; Fulenwider, D.O.	2000	Six sigma, e-commerce pose new challenges	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations	4	1	33	7	31-37	USA	Academy

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					Research & Management Science							
83	Munro, R.A.	2000	Linking six sigma with QS-9000	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	4	1	33	5	47-53	-	-
84	Jin, T.D.; Su, P.	2005	Minimize system reliability variability based on six-sigma criteria considering component operational uncertainties	Annual Reliability and Maintainability Symposium, 2005 Proceedings	Engineering, Multidisciplinary	4	0			214-219	USA	Industry
85	Hutchins, G.	2000	The branding of six sigma	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	4	0	33	9	120-121	-	-
86	Nave, D.	2002	How to compare six sigma, lean and the theory of constraints - a framework for choosing what's best for your organization	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	5	3	35	3	73-78	-	-
87	Sokovic, M.; Pavletic, D.; Fakin, S.	2005	Application of six sigma methodology for process design	Journal of Materials Processing Technology	Engineering, Industrial; Engineering, Manufacturing; Materials Science, Multidisciplinary	5	1	162		777-783	Slovenia	Academy
88	Montgomery, D.C.; Burdick, R.K.; Lawson, C.A.; Molnau, W.E.; Zenzen, F; Jennings, C.L.; Shah, H.K; Sebert, D.A.; Bowser, M.D.; Holcomb, D.R.	2005	A University-based six sigma program	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	5	1	21	3	243-248	USA	Academy
89	Breyfogle, F.W.	2002	Golf and six sigma - use six sigma metrics to drive proper process behavior	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	5	1	35	11	83-85	USA	Industry
90	Pearson, T.A.	2001	Measure for six sigma success	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	5	1	34	2	35-40	USA	Industry
91	Wheeler, J.M.	2002	Getting started: six-sigma control of chemical operations	Chemical Engineering Progress	Engineering, Chemical	6	5	98	6	76-81	USA	Industry
92	Pavletic, D.; Fakin, S.; Sokovic, M.	2004	Six sigma in process design	Strojniski Vestnik-Journal of Mechanical Engineering	Engineering, Mechanical	6	2	50	3	157-167	Croatia	Academy
93	Jacobson, J.M.; Johnson, M.E.	2006	Lean and six sigma: not for amateurs - second in a 2-part series	Labmedicine	Medical Laboratory Technology	6	1	37	3	140-145	USA	Industry
94	Blakeslee, J.A.	1999	Implementing the six sigma solution	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	6	1	32	7	77-85	USA	Industry
95	Ashton, H.C.	1998	A statistical quality-driven approach to in-polymer additive analysis	Angewandte Makromolekulare Chemie	Polymer Science	6	0	262		9-23	Netherlands	Industry
96	Doble, M.	2005	Understand the myths surrounding six sigma	Hydrocarbon Processing	Energy & Fuels; Engineering, Chemical; Engineering, Petroleum	6	0	84	3	80-82	India	Academy
97	Keene, S.; Alberti, D.; Henby, G.; Brohinsky, A.J.; Tayur, S.	2006	Caterpillar's building construction products division improves and stabilizes product availability	Interfaces	Management; Operations Research & Management Science	6	0	36	4	283-294	USA	Industry
98	Park, S.; Gil, Y.	2006	How Samsung transformed its corporate R&D center	Research-Technology Management	Business; Engineering, Industrial; Management	6	0	49	4	24-29	South Korea	Academy
99	Arul, K.; Kohli, H.	2004	Six sigma for software application of hypothesis tests to software data	Software Quality Journal	Computer Science, Software Engineering	6	0	12	1	29-42	Scotland	Industry
100	Hahn, G.; Hoerl, R.	1998	Key challenges for statisticians in business and industry	Technometrics	Statistics & Probability	7	14	40	3	195-200	USA	Industry
101	Koban, M.E.	2004	Using six sigma tools to evaluate pigment dispersant demand performance	JCT Coatingstech	Chemistry, Applied; Materials Science, Coatings & Films	7	1	1	2	28-33	USA	Industry
102	Van Den Heuvel, J.; Does, R.J.M.M.; Vermaat, M.B.	2004	Six sigma in a Dutch hospital: does it work in the nursing department?	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	7	1	20	5	419-426	Netherlands	Industry

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103	Maleyeff, J.; Krayenvenger, D.E.	2004	Goal setting with six sigma mean shift determination	Aircraft Engineering and Aerospace Technology	Engineering, Aerospace	7	0	76	6	577-583	USA	Academy
104	Sokovic, M.; Jurecic, M.; Kramar, A.	2004	Reducing the costs of shipping automotive products by implementing a six sigma methodology	Strojniski Vestnik-Journal of Mechanical Engineering	Engineering, Mechanical	7	0	50	4	219-228	Slovenia	Academy
105	Hahn, G.J.; Hill, W.J.; Hoerl, R.W.; Zinkgraf, S.A.	1999	The impact of six sigma improvement - a glimpse into the future of statistics	American Statistician	Statistics & Probability	8	19	53	3	208-215	USA	Industry
106	Condel, J.L.; Sharbaugh, D.T.; Raab, S.S.	2004	Error-free pathology: applying lean production methods to anatomic pathology	Clinics in Laboratory Medicine	Medical Laboratory Technology	8	10	24	4	865-900	USA	Academy
107	Krouwer, J.	2002	Using a learning curve approach to reduce laboratory errors	Accreditation and Quality Assurance	Chemistry, Analytical; Instruments & Instrumentation	8	5	7	11	461-467	USA	Industry
108	Pheng, L.S.; Hui, M.S.	2004	Implementing and applying six sigma in construction	Journal of Construction Engineering and Management-ASCE	Construction & Building Technology; Engineering, Industrial; Engineering, Civil	8	0	130	4	482-489	Singapore	Academy
109	Sokovic, M.; Pavletic, D.; Matkovic, R.	2005	Measuring-system analysis for quality assurance in a six-sigma process	Strojniski Vestnik-Journal of Mechanical Engineering	Engineering, Mechanical	8	0	51	9	589-599	Slovenia	Academy
110	Nevalainen, D.; Berte, L.; Kraft, C.; Leigh, E.; Picaso, L.; Morgan, T.	2000	Evaluating laboratory performance on quality indicators with the six sigma scale	Archives of Pathology & Laboratory Medicine	Medical Laboratory Technology; Medicine, Research & Experimental; Pathology	9	22	124	4	516-519	USA	Industry
111	Kenett, R.S.; Coleman, S.; Stewardson, D.	2003	Statistical efficiency: the practical perspective	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	9	3	19	4	265-272	England	Academy
112	Kim, H.S.; Kim, C.B.; Yim, H.J.	2003	Quality improvement for brake judder using design for six sigma with response surface method and sigma based robust design	International Journal of Automotive Technology	Engineering, Mechanical; Transportation Science & Technology	9	2	4	4	193-201	South Korea	Academy
113	Lee, J.	2003	Smart products and service systems for e-business transformation	International Journal of Technology Management	Engineering, Multidisciplinary; Management; Operations Research & Management Science	9	2	26	1	45-52	USA	Academy
114	Anderson-Cook, C.M.; Patterson, A.; Hoerl, R.	2005	A structured problem-solving course for graduate students: exposing students to six sigma as part of their university training	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	9	2	21	3	249-256	USA	Industry
115	Tylutki, T.P.; Fox, D.G.	2002	Mooooving toward six sigma	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	9	1	35	2	34-41	USA	Academy
116	Sun, Z.H.; Ranek, M.; Voight, M.; Steyer, G.	2006	Manufacturing tolerances and axle system NVH performance	Sound and Vibration	Acoustics; Engineering, Mechanical; Mechanics	9	0	40	4	12-19	USA	Industry
117	Tang, L.C.; Than, S.E.; Ang, B.W.	1997	A graphical approach to obtaining confidence limits of C-pk	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	10	9	13	6	337-346	Singapore	Academy
118	Koonce, D.; Judd, R; Sormaz, D.; Masel, D.T.	2003	A hierarchical cost estimation tool	Computers in Industry	Computer Science, Interdisciplinary Applications	10	7	50	3	293-302	USA	Academy
119	Rowlands, H.; Antony, J.	2003	Application of design of experiments to a spot welding process	Assembly Automation	Automation & Control Systems; Engineering, Manufacturing	10	3	23	3	273-279	Wales	Academy
120	Gnibus, R.J.	2000	Six sigma's missing link - understanding the quality tool needed to calculate sigma ratings	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	10	1	33	11	77-80	Brazil	Industry
121	Doble, M.	2003	Putting six sigma processes to work	Chemical Engineering	Engineering, Chemical	10	0	110	12	62-67	India	Academy
122	Tong, J.P.C.; Tsung, F.; Yen, B.P.C.	2004	A DMAIC approach to printed circuit board quality improvement	International Journal of Advanced Manufacturing Technology	Automation & Control Systems; Engineering, Manufacturing	11	4	23	7/8	523-531	Hong Kong	Academy
123	Coleman, S.Y.; Arunakumar, G.; Foldvary, F.; Feltham, R.	2001	SPC as a tool for creating a successful business measurement framework	Journal of Applied Statistics	Statistics & Probability	11	3	28	3/4	325-334	England	Academy

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125	Rajagopal, R.; Del Castillo, E.	2007	A Bayesian approach for multiple criteria decision making with applications in design for six sigma	Journal of the Operational Research Society	Management; Operations Research & Management Science	11	0	58	6	779-790	USA	Academy
126	Kumi, S.; Morrow, J.	2006	Improving self service the six sigma way at Newcastle University Library	Program-Electronic Library and Information Systems	Computer Science, Information Systems; Information Science & Library Science	11	0	40	2	123-136	England	Academy
127	Hahn, G.J.	2005	Six sigma: 20 key lessons learned	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	12	4	21	3	225-233	USA	Industry
128	Pavletic, D.; Sokovic, M.	2002	Six sigma: A complex quality inititative	Strojniski Vestnik-Journal of Mechanical Engineering	Engineering, Mechanical	12	1	48	3	158-168	Croatia	Academy
129	Van Merode, F.; Molema, H.; Goldschmidt, H.	2004	GUM and six sigma approaches positioned as deterministic tools in quality target engineering	Accreditation and Quality Assurance	Chemistry, Analytical; Instruments & Instrumentation	12	0	10	1/2	32-36	Netherlands	Academy
130	Kang, J.O.; Kim, M.H.; Hong, S.E.; Jung, J.H.; Song, M.J.	2005	The application of the six sigma program for the quality management of the PACS	American Journal of Roentgenology	Radiology, Nuclear Medicine & Medical Imaging	12	0	185	5	1361-1365	South Korea	Academy
131	Parker, B.M.; Henderson, J.M.; Vitagliano, S.; Nair, B.G.; Petre, J.; Maurer, W.G.; Roizen, M.F.; Weber, M.; Dewitt, L.; Beedlow, J.; Fahey, B.; Calvert, A.; Ribar, K.; Gordon, S.	2007	Six sigma methodology can be used to improve adherence for antibiotic prophylaxis in patients undergoing noncardiac surgery	Anesthesia and Analgesia	Anesthesiology	12	0	104	1	140-146	USA	Industry
132	Sokovic, M.; Pavletic, D.	2007	Quality improvement - PDCA cycle vs. DMAIC and DFSS	Strojniski Vestnik-Journal of Mechanical Engineering	Engineering, Mechanical	12	0	53	6	369-378	Slovenia	Academy
133	Frings, G.W.; Grant, L.	2005	Who moved my sigma... effective implementation of the six sigma methodology to hospitals	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	13	2	21	3	311-328	USA	Academy
134	Lucas, J.M.	2002	The essential six sigma - how successful six sigma implementation can improve the bottom line	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	13	2	35	1	27-31	USA	Industry
135	Murugappan, M.; Keeni, G.	2003	Blending CMM and six sigma to meet business goals	IEEE Software	Computer Science, Software Engineering	13	1	20	2	42-49	India	Industry
136	Chen, K.S.; Hsu, C.H.; Ouyang, L.Y.	2007	Applied product capability analysis chart in measure step of six sigma	Quality & Quantity	Social Sciences, Interdisciplinary; Statistics & Probability	13	0	41	3	387-400	Taiwan	Academy
137	Pan, J.N.	2006	Evaluating the gauge repeatability and reproducibility for different industries	Quality & Quantity	Social Sciences, Interdisciplinary; Statistics & Probability	13	0	40	4	499-518	Taiwan	Academy
138	Caulcutt, R.	2004	Black belt types	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	13	0	20	5	427-432	England	Industry
139	Caulcutt, R.	2001	Why is six sigma so successful?	Journal of Applied Statistics	Statistics & Probability	14	4	28	3/4	301-306	England	Industry
140	Edgeman, R.L.; Bigio, D.; Ferleman, T.	2005	Six sigma and business excellence: strategic and tactical examination of IT service level Management at the Office of the Chief Technology Officer of Washington, DC	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	14	1	21	3	257-273	USA	Academy
141	D'Angelo, R.; Zarbo, R.J.	2007	The Henry Ford production system: measures of process defects and waste in surgical pathology as a basis for quality improvement initiatives	American Journal of Clinical Pathology	Pathology	14	0	128	3	423-429	USA	Industry
142	Deshpande, P.B.; Makker, S.L.; Goldstein, M.	1999	Boost competitiveness via six sigma	Chemical Engineering Progress	Engineering, Chemical	15	4	95	9	65-70	USA	Academy
143	Saengpongpaew, P.; Sirinaovakul, B.	1997	Computer-aided process control (CAPC) for the semiconductor industry	International Journal of Materials & Product Technology	Materials Science, Multidisciplinary	15	1	12	1	68-81	Thailand	Academy

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145	Snee, R.D.	2005	Leading business improvement: a new role for statisticians and quality professionals	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	15	1	21	3	235-242	USA	Industry
146	Duquesnoy, L.; Berger, J.L.; Prevot, P.; Sandoz-Guermond, F.	2002	SIMPA: a training platform in work station including computing tutors	Intelligent Tutoring Systems	Computer Science, Theory & Methods	15	0	2363		507-520	France	Industry
147	Park, T.W.; Sohn, H.S.	2005	Quality improvement of vehicle drift using statistical six sigma tools	International Journal of Automotive Technology	Engineering, Mechanical; Transportation Science & Technology	15	0	6	6	625-633	South Korea	Industry
148	Grove, D.; Campean, F.; Henshall, E.	2005	A course in statistical engineering	International Journal of Engineering Education	Education, Scientific Disciplines; Engineering, Multidisciplinary	15	0	21	3	502-511	England	Academy
149	Lasky, F.D.; Boser, R.B.	1997	Designing in quality through design control: a manufacturer's perspective	Clinical Chemistry	Medical Laboratory Technology	16	9	43	5	866-872	USA	Industry
150	Bassett, M.H.; Gardner, L.L.; Steele, K.	2004	Dow AgroSciences uses simulation-based optimization to schedule the new-product development process	Interfaces	Management; Operations Research & Management Science	16	1	34	6	426-437	USA	Industry
151	Knowles, G.; Vickers, G.; Anthony, J.	2003	Implementing evaluation of the measurement process in an automotive manufacturer: a case study	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	16	1	19	5	397-410	England	Academy
152	Stotsky, A.	2007	Statistical algorithms for engine knock detection	International Journal of Automotive Technology	Engineering, Mechanical; Transportation Science & Technology	16	0	8	3	259-268	Sweeden	Industry
153	Goh, T.N.	2001	A pragmatic approach to experimental design in industry	Journal of Applied Statistics	Statistics & Probability	17	8	28	3/4	391-398	Singapore	Academy
154	Griffiths, V.; Ahmed-Jushuf, İ.	2007	Releasing capacity in sexual health through modernization	International Journal of Std & Aids	Immunology; Infectious Diseases	17	2	18	5	299-304	England	Academy
155	Lee, S.W.; Kwon, O.J.	2006	Robust airfoil shape optimization using design for six sigma	Journal of Aircraft	Engineering, Aerospace	17	0	43	3	843-846	South Korea	Academy
156	Verma, A.K.; Ghadmode, A.	2004	An integrated lean implementation model for fleet repair and maintenance	Naval Engineers Journal	Engineering, Marine; Engineering, Civil; Oceanography	17	0	116	4	79-89	USA	Academy
157	Deshpande, P.B.	1998	Emerging technologies and six sigma	Hydrocarbon Processing	Energy & Fuels; Engineering, Chemical; Engineering, Petroleum	18	2	77	4	55-60	USA	Industry
158	Li, Y.Q.; Cui, Z.S.; Ruan, X.Y.; Zhang, D.J.	2006	CAE-based six sigma robust optimization for deep-drawing process of sheet metal	International Journal of Advanced Manufacturing Technology	Automation & Control Systems; Engineering, Manufacturing	18	1	30	7/8	631-637	China	Academy
159	Riley, J.B.; Justison, G.A.; Povrzenic, D.; Zabetakis, P.A.	2002	Designing an integrated extracorporeal therapy service quality system	Therapeutic Apheresis	Hematology	18	1	6	4	282-287	USA	Industry
160	Gurunatha, T.; Siegel, R.P.	2003	Applying quality tools to reliability: a 12-step six-sigma process to accelerate reliability growth in product design	Annual Reliability and Maintainability Symposium, 2003 Proceedings	Engineering, Multidisciplinary	19	1			562-567	USA	Industry
161	Su, C.T.; Chiang, T.L.; Chiao, K.	2005	Optimizing the IC delamination quality via six-sigma approach	IEEE Transactions on Electronics Packaging Manufacturing	Engineering, Manufacturing	19	0	28	3	241-248	Taiwan	Academy
162	Hinckley, C.M.; Barkan, P.	1996	Selecting the best defect reduction methodology	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	19	0	12	6	411-420	USA	Industry
163	Cechich, A.; Piattini, M.	2005	Filtering COTS components through an improvement-based process	Cots-Based Software Systems, Proceedings	Computer Science, Theory & Methods	20	1	3412		112-121	Argentina	Academy
164	Ribardo, C.; Allen, T.T.	2003	An alternative desirability function for achieving 'six sigma' quality	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	20	1	19	3	227-240	USA	Academy
165	Hwang, Y.D.	2006	The practices of integrating manufacturing execution system and six sigma methodology	International Journal of Advanced Manufacturing Technology	Automation & Control Systems; Engineering, Manufacturing	20	0	30	7/8	761-768	Taiwan	Academy
166	Sinnadurai, N.	2000	Reliability of new packaging concepts	Microelectronics Reliability	Engineering, Electrical & Electronic; Nanoscience & Nanotechnology; Physics,	20	0	40	7	1073-1080	England	Industry

No	Authors	Year	Title	Journal Name	Subject Categories	Number of References	Times Cited	Volume	No	Pages	Country	Affiliation
					Applied							
167	Bisgaard, S.	2005	Innovation, ENBIS and the importance of practice in the development of statistics	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	20	0	21	5	429-438	USA	Academy
168	Aksit, M.F.; Chupp, R.E.; Dinc, O.S.; Demiroglu, M.	2002	Advanced seals for industrial turbine applications: design approach and static seal development	Journal of Propulsion and Power	Engineering, Aerospace	21	2	18	6	1254-1259	Turkey	Academy
169	Yeh, D.Y.; Cheng, C.H.; Chi, M.L.	2007	A modified two-tuple FLC model for evaluating the performance of SCM: by the six sigma DMAIC process	Applied Soft Computing	Computer Science, Artificial Intelligence; Computer Science, Interdisciplinary Applications	21	0	7	3	1027-1034	Taiwan	Academy
170	Prabhakaran, R.T.D; Babu, B.J.C; Agrawal, V.P.	2006	Design for 'X'-abilities of RTM products - a graph theoretic approach	Concurrent Engineering-Research and Applications	Computer Science, Interdisciplinary Applications; Engineering, Manufacturing; Operations Research & Management Science	21	0	14	2	151-161	India	Academy
171	Chen, K.S.; Wang, C.H.; Chen, H.T.	2006	A MAIC approach to TFT-LCD panel quality improvement	Microelectronics Reliability	Engineering, Electrical & Electronic; Nanoscience & Nanotechnology; Physics, Applied	21	0	46	7	1189-1198	Taiwan	Academy
172	Arvidsson, M.; Gremyr, İ.; Johansson, P.	2003	Use and knowledge of robust design methodology: a survey of Swedish industry	Journal of Engineering Design	Engineering, Multidisciplinary	22	7	14	2	129-143	Sweeden	Academy
173	Garg, D.; Narahari, Y.; Viswanadham, N.	2004	Design of six sigma supply chains	IEEE Transactions on Automation Science and Engineering	Automation & Control Systems	22	3	1	1	38-57	India	Academy
174	Ali, O.G.; Chen, Y.T.	1999	Design quality and robustness with neural networks	IEEE Transactions on Neural Networks	Computer Science, Artificial Intelligence; Computer Science, Hardware & Architecture; Computer Science, Theory & Methods; Engineering, Electrical & Electronic	22	3	10	6	1518-1527	USA	Industry
175	Raisinghani, M.S.; Ette, H.; Pierce, R.; Cannon, G.; Daripaly, P.	2005	Six sigma: concepts, tools, and applications	Industrial Management & Data Systems	Computer Science, Interdisciplinary Applications; Engineering, Industrial	23	8	105	3/4	491-505	USA	Academy
176	Dassau, E.; Zadok, İ.; Lewin, D.R.	2006	Combining six-sigma with integrated design and control for yield enhancement in bioprocessing	Industrial & Engineering Chemistry Research	Engineering, Chemical	23	0	45	25	8299-8309	Israel	Academy
177	Frankel, H.L.; Crede, W.B.; Topal, J.E.; Roumanis, S.A.; Devlin, M.W.; Foley, A.B.	2005	Use of corporate six sigma performance-improvement strategies to reduce incidence of catheter-related bloodstream infections in a surgical ICU	Journal of the American College of Surgeons	Surgery	24	5	201	3	349-358	USA	Academy
178	Chan, K.K.; Spedding, T.A.	2001	On-line optimization of quality in a manufacturing system	International Journal of Production Research	Engineering, Industrial; Engineering, Manufacturing; Operations Research & Management Science	24	3	39	6	1127-1145	England	Academy
179	Eldridge, N.E.; Woods, S.S.; Bonello, R.S.; Clutter, K.; Ellingson, L.; Harris, M.A.; Livingston, B.K.; Bagian, J.P.; Danko, L.H.; Dunn, E.J.; Parlier, R.L.; Pederson, C.; Reichling, K.J.; Roselle, G.A.; Wright, S.M.	2006	Using the six sigma process to implement the centers for disease control and prevention guideline for hand hygiene in 4 intensive care units	Journal of General Internal Medicine	Medicine, General & Internal	24	3	21		35-42	USA	Industry
180	Patterson, A.; Bonissone, P.; Pavese, M.	2005	Six sigma applied throughout the lifecycle of an automated decision system	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	24	3	21	3	275-292	USA	Industry
181	De Mast, J.; Schippers, W.A.J.; Does, R.J.M.M.; Van Den Heuvel, E.R.	2000	Steps and strategies in process improvement	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	25	2	16	4	301-311	Netherlands	Academy
182	Neagu, R.; Hoerl, R.	2005	A six sigma approach to predicting corporate defaults	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	25	1	21	3	293-309	USA	Industry
183	Hsieh, C.T.; Lin, B.; Manduca, B.	2007	Information technology and six sigma implementation	Journal of Computer Information Systems	Computer Science, Information Systems	25	0	47	4	1-10	USA	Academy

No	Authors	Year	Title	Journal Name	Subject Categories	Number of References	Times Cited	Volume	No	Pages	Country	Affiliation
184	Buell, R.S.; Turnipseed, S.P.	2004	Application of lean six sigma in oilfield operations	SPE Production & Facilities	Engineering, Petroleum	25	0	19	4	201-208	-	-
185	Forouraghi, B.	2002	Worst-case tolerance design and quality assurance via genetic algorithms	Journal of Optimization Theory and Applications	Operations Research & Management Science; Mathematics, Applied	27	1	113	2	251-268	USA	Academy
186	Banuelas, R.; Antony, J.; Brace, M.	2005	An application of six sigma to reduce waste	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	27	0	21	6	553-570	Scotland	Academy
187	Hoerl, R.W.	2001	Six sigma black belts: what do they need to know?	Journal of Quality Technology	Engineering, Industrial; Operations Research & Management Science; Statistics & Probability	28	15	33	4	391-406	USA	Industry
188	Hahn, G.J.	2002	Deming and the proactive statistician	American Statistician	Statistics & Probability	28	1	56	4	290-298	USA	Industry
189	Bowman, A.; Schmee, J.	2004	Estimating sensitivity of process capability modeled by a transfer function	Journal of Quality Technology	Engineering, Industrial; Operations Research & Management Science; Statistics & Probability	28	0	36	2	223-239	USA	Academy
190	Fowler, J.W.; Rose, O.	2004	Grand challenges in modeling and simulation of complex manufacturing systems	Simulation-Transactions of the Society For Modeling and Simulation International	Computer Science, Interdisciplinary Applications; Computer Science, Software Engineering	29	2	80	9	469-476	USA	Academy
191	Kazmer, D.; Lotti, C.; Bretas, R.E.S.; Zhu, L.	2004	Tuning and control of dimensional consistency in molded products	Advances in Polymer Technology	Engineering, Chemical; Polymer Science	29	1	23	3	163-175	USA	Academy
192	Du, X.P.; Chen, W.	2000	Towards a better understanding of modeling feasibility robustness in engineering design	Journal of Mechanical Design	Engineering, Mechanical	30	32	122	4	385-394	USA	Academy
193	Chi, H.M.; Ersoy, O.K.; Moskowitz, H.; Altinkemer, K.	2007	Toward automated intelligent manufacturing systems (AIMS)	Informs Journal on Computing	Computer Science, Interdisciplinary Applications; Operations Research & Management Science	30	0	19	2	302-312	USA	Academy
194	Prabhakaran, R.T.D.; Babu, B.J.C.; Agrawal, V.P.	2006	Quality modeling and analysis of polymer composite products	Polymer Composites	Materials Science, Composites; Polymer Science	30	0	27	4	329-340	India	Academy
195	Yang, J.H.; Lee, K.Y.	2005	Application of a design of experiments approach to the reliability of a PBGA package	Soldering & Surface Mount Technology	Engineering, Manufacturing; Engineering, Electrical & Electronic; Materials Science, Multidisciplinary; Metallurgy & Metallurgical Engineering	30	0	17	3	43-53	South Korea	Industry
196	Koch, P.N.; Yang, R.J.; Gu, L.	2004	Design for six sigma through robust optimization	Structural and Multidisciplinary Optimization	Computer Science, Interdisciplinary Applications; Engineering, Multidisciplinary; Mechanics	31	8	26	3/4	235-248	USA	Industry
197	De Mast, J.	2003	Quality improvement from the viewpoint of statistical method	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	31	4	19	4	255-264	Netherlands	Academy
198	Mahesh, M.; Wong, Y.S.; Fuh, J.Y.H.; Loh, H.T.	2006	A six-sigma approach for benchmarking of RP&M processes	International Journal of Advanced Manufacturing Technology	Automation & Control Systems; Engineering, Manufacturing	31	0	31	3/4	374-387	Singapore	Academy
199	Dejaegher, B.; Jimidar, M.; De Smet, M.; Cockaerts, P.; Smeyers-Verbeke, J.; Vander Heyden, Y.	2006	Improving method capability of a drug substance HPLC assay	Journal of Pharmaceutical and Biomedical Analysis	Chemistry, Analytical; Pharmacology & Pharmacy	32	2	42	2	155-170	Belgium	Industry
200	Kumar, M.; Antony, J.; Singh, R.K.; Tiwari, M.K.; Perry, D.	2006	Implementing the lean sigma framework in an Indian SME: a case study	Production Planning & Control	Engineering, Industrial; Engineering, Manufacturing; Operations Research & Management Science	32	0	17	4	407-423	Scotland	Academy
201	Reh, S.; Beley, J.D.; Mukherjee, S.; Khor, E.H.	2006	Probabilistic finite element analysis using ANSYS	Structural Safety	Engineering, Civil	33	1	28	1/2	17-43	Germany	Academy
202	Feng, C.X.J.; Kusiak, A.	1997	Robust tolerance design with the integer programming approach	Journal of Manufacturing Science and Engineering-Transactions of the ASME	Engineering, Manufacturing; Engineering, Mechanical	34	24	119	4A	603-610	USA	Academy
203	Antony, J.; Kumar, M.; Tiwari, M.K.	2005	An application of six sigma methodology to reduce the engine- overheating problem in an automotive company	Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture	Engineering, Manufacturing; Engineering, Mechanical	35	1	219	8	633-646	Scotland	Academy

No	Authors	Year	Title	Journal Name	Subject Categories	Number of References	Times Cited	Volume	No	Pages	Country	Affiliation
204	Anand, R.B.; Shukla, S.K.; Ghorpade, A.; Tiwari, M.K.; Shankar, R.	2007	Six sigma-based approach to optimize deep drawing operation variables	International Journal of Production Research	Engineering, Industrial; Engineering, Manufacturing; Operations Research & Management Science	37	0	45	10	2365-2385	India	Academy
205	Kwak, Y.H.; Anbari, F.T.	2006	Benefits, obstacles, and future of six sigma approach	Technovation	Engineering, Industrial; Management; Operations Research & Management Science	39	1	26	5/6	708-715	USA	Academy
206	Kang, N.; Kim, J.; Park, Y.	2007	Integration of marketing domain and R&D domain in NPD design process	Industrial Management & Data Systems	Computer Science, Interdisciplinary Applications; Engineering, Industrial	39	0	107	5/6	780-801	South Korea	Academy
207	Subbarayan, G.; Li, Y.; Mahajan, R.L.	1996	Reliability simulations for solder joints using stochastic finite element and artificial neural network models	Journal of Electronic Packaging	Engineering, Electrical & Electronic; Engineering, Mechanical	40	5	118	3	148-156	USA	Academy
208	Hwang, Y.D.	2006	The practices of integrating manufacturing execution systems and six sigma methodology	International Journal of Advanced Manufacturing Technology	Automation & Control Systems; Engineering, Manufacturing	41	0	31	1/2	145-154	Taiwan	Academy
209	Noorbatcha, İ.; Razali, R.B.A.	1999	Molecular orbital analysis of the reaction paths for termolecular reactions	Indian Journal of Chemistry Section A-Inorganic Bio-Inorganic Physical Theoretical & Analytical Chemistry	Chemistry, Multidisciplinary	42	0	38	1	4-9	Malaysia	Academy
210	Sulek, J.M.; Marucheck, A.; Lind, M.R.	2006	Measuring performance in multi-stage service operations: an application of cause selecting control charts	Journal of Operations Management	Management; Operations Research & Management Science	42	0	24	5	711-727	USA	Academy
211	Tang, L.C.; Goh, T.N.; Lam, S.W.; Zhang, C.W.	2007	Fortification of six sigma: expanding the DMAIC toolset	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	43	1	23	1	3-18	Singapore	Academy
212	Cechich, A.; Piattini, M.	2007	Early detection of COTS component functional suitability	Information and Software Technology	Computer Science, Information Systems; Computer Science, Software Engineering	44	1	49	2	108-121	Argentina	Academy
213	De Mast, J.; Bergman, M.	2006	Hypothesis generation in quality improvement projects: Approaches for exploratory studies	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	46	1	22	7	839-850	Netherlands	Academy
214	Sequeira, R.; Genaidy, A.; Shell, R.; Karwowski, W.; Weckman, G.; Salem, S.	2006	The nano enterprise: a survey of health and safety concerns, considerations, and proposed improvement strategies to reduce potential adverse effects	Human Factors and Ergonomics in Manufacturing	Engineering, Manufacturing; Ergonomics	46	0	16	4	343-368	USA	Academy
215	Kiechle, F.L.	2001	Hospital laboratory survival in a cost control environment	Journal of Clinical Ligand Assay	Biochemical Research Methods; Immunology; Medical Laboratory Technology	52	0	24	4	235-238	USA	Industry
216	Pawlicki, T.; Mundt, A.J.	2007	Quality in radiation oncology	Medical Physics	Radiology, Nuclear Medicine & Medical Imaging	52	0	34	5	1529-1534	USA	Academy
217	Mizuyama, H.	2005	Statistical robust design of a complex system through a sequential approach	Journal of Engineering Design	Engineering, Multidisciplinary	53	2	16	2	259-276	Japan	Academy
218	Linderman, K.; Schroeder, R.G.; Zaheer, S.; Choo, A.S.	2003	Six sigma: a goal-theoretic perspective	Journal of Operations Management	Management; Operations Research & Management Science	58	16	21	2	193-203	USA	Academy
219	Goh, T.N.	2002	A strategic assessment of six sigma	Quality and Reliability Engineering International	Engineering, Multidisciplinary; Operations Research & Management Science	59	3	18	5	403-410	Singapore	Academy
220	Chassin, M.R.	1998	Is health care ready for six sigma quality?	Milbank Quarterly	Health Care Sciences & Services; Health Policy & Services	61	105	76	4	565-592	USA	Academy
221	Subramanian, G.H.; Jiang, J.J.; Klein, G.	2007	Software quality and IS project performance improvements from software development process maturity and IS implementation strategies	Journal of Systems and Software	Computer Science, Software Engineering; Computer Science, Theory & Methods	63	0	80	4	616-627	USA	Academy
222	Linderman, K.; Schroeder, R.G.; Choo, A.S.	2006	Six sigma: The role of goals in improvement teams	Journal of Operations Management	Management; Operations Research & Management Science	66	0	24	6	779-790	USA	Academy
223	Davies, H.T.O.	2001	Exploring the pathology of quality failings: measuring quality is not the problem - changing it is	Journal of Evaluation in Clinical Practice	Health Care Sciences & Services; Medical Informatics; Medicine, General & Internal	70	4	7	2	243-251	Scotland	Academy

No	Authors	Year	Title	Journal Name	Subject Categories	Number of References	Times Cited	Volume	No	Pages	Country	Affiliation
224	Shoaf, C.; Genaidy, A.; Karwowski, W.; Huang, S.H.	2004	Improving performance and quality of working life: a model for organizational health assessment in emerging enterprises	Human Factors and Ergonomics in Manufacturing	Engineering, Manufacturing; Ergonomics	70	3	14	1	81-95	USA	Academy
225	Becich, M.J.; Gilbertson, J.R.; Gupta, D.; Patel, A.; Grzybicki, D.M.; Raab, S.S.	2004	Pathology and patient safety: the critical role of pathology reduction and informatics in error quality initiatives	Clinics in Laboratory Medicine	Medical Laboratory Technology	78	8	24	4	913-944	USA	Academy
226	Spivack, J.L.; Cawse, J.N.; Whisenhunt, D.W.; Johnson, B.F.; Shalyaev, K.V.; Male, J.; Pressman, E.J.; Ofori, J.Y.; Soloveichik, G.L.; Patel, B.P.; Chuck, T.L.; Smith, D.J.; Jordan, T.M.; Brennan, M.R.; Kilmer, R.J.; Williams, E.D.	2003	Combinatorial discovery of metal co-catalysts for the carbonylation of phenol	Applied Catalysis A-General	Chemistry, Physical; Environmental Sciences	84	10	254	1	5-25	USA	Industry
227	Choo, A.S.; Linderman, K.W.; Schroeder, R.G.	2007	Method and psychological effects on learning behaviors and knowledge creation in quality improvement projects	Management Science	Management; Operations Research & Management Science	87	0	53	3	437-450	USA	Academy
228	Graf, H.J.; Seward, J.; Baird, S.D.; Yu, S.	2004	The extruder - a look into the "black box"	Kautschuk Gummi Kunststoffe	Engineering, Chemical; Polymer Science	22	0	57	4	148-150	Canada	Industry
229	Chen, J.M.; Tsou, J.C.	2003	An optimal design for process quality improvement: modelling and application	Production Planning & Control	Engineering, Industrial; Engineering, Manufacturing; Operations Research & Management Science	16	3	14	7	603-612	Taiwan	Academy
230	Lienard, J.; Sureda, F.; Finet, G.	2002	The 6 sigma quality approach for quantitative arteriography performance improvement	International Journal of Cardiovascular Imaging	Cardiac & Cardiovascular Systems; Radiology, Nuclear Medicine & Medical Imaging	11	1	18	2	77-92	France	Industry
231	Harrold, D.	2001	Push the 6 sigma limits	Control Engineering	Automation & Control Systems; Engineering, Electrical & Electronic; Instruments & Instrumentation	0	0	48	2	63-66	-	-
232	Huang, C.Y.; Srihari, K.; Borgesen, P.	2000	Optimisation of the substrate preheat temperature for the encapsulation of flip chip devices	International Journal of Advanced Manufacturing Technology	Automation & Control Systems; Engineering, Manufacturing	5	2	16	1	55-64	USA	Academy
233	Petrova, T.; Kazmer, D.	1999	Incorporation of phenomenological models in a hybrid neural network for quality control of injection molding	Polymer-Plastics Technology and Engineering	Polymer Science	23	2	38	1	1-18	USA	Academy
234	Al-Tamimi, A.K.; Bardan, M.	2006	Integration of quality control and GIS to improve water network in the city of Sharjah	Journal of Water Supply Research and Technology-Aqua	Engineering, Civil; Water Resources	9	0	55	6	401-412	United Arab Emirates	Academy
235	Swan, P.A.; Zukowski, J.A.	1995	Manufacturing technologies, the "key" to a 66 small satellite system	Space Technology-Industrial and Commercial Applications	Engineering, Aerospace	1	0	15	4	181-185	USA	Industry
236	Fontenot, G.; Behara, R.; Gresham, A.	1994	6 sigma in customer satisfaction	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	0	3	27	12	73-76	USA	Industry
237	Tadikamalla, P.R.	1994	The confusion over 6-sigma quality	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	0	3	27	11	83-85	USA	Academy
238	Head, G.E.	1994	6-sigma software using cleanroom software engineering techniques	Hewlett-Packard Journal	Computer Science, Hardware & Architecture; Engineering, Electrical & Electronic; Instruments & Instrumentation	0	0	45	3	40-50	USA	Industry
239	Smith, B.	1993	6-sigma design	IEEE Spectrum	Engineering, Electrical & Electronic	0	11	30	9	43-47	USA	Industry
240	Mcfadden, F.R.	1993	6-sigma quality programs	Quality Progress	Engineering, Multidisciplinary; Engineering, Industrial; Management; Operations Research & Management Science	0	8	26	6	37-42	USA	Academy

No	Authors	Year	Title	Journal Name	Subject Categories	Number of References	Times Cited	Volume	No	Pages	Country	Affiliation
241	Cooper, D.W.; Babcock, J.V.; Dipietro, F.	1993	Initiating 6 sigma-statistical quality-control techniques for cleanroom settling monitors	Solid State Technology	Engineering, Electrical & Electronic; Physics, Applied; Physics, Condensed Matter	2	1	36	2	37-37	USA	Industry
242	Fieler, P.E.; Loverro, N.	1991	Defects tail off with 6-sigma manufacturing	IEEE Circuits and Devices Magazine	Engineering, Electrical & Electronic; Instruments & Instrumentation	3	2	7	5	18-18	USA	Industry
243	Tsou, J.C.; Chen, J.M.	2005	Case study: quality improvement model in a car seat assembly line	Production Planning & Control	Engineering, Industrial; Engineering, Manufacturing; Operations Research & Management Science	22	1	16	7	681-690	Taiwan	Academy
244	Min, S.J.; Bang, S.H.	2005	Structural topology design considering reliability	Advances in Fracture and Strength, Pts 1- 4	Materials Science, Ceramics; Materials Science, Composites	8	0	297-300		1901-1906	South Korea	Academy
245	Geismar, D.; White, G.	2004	Process reliability and flexibility - a tool to improve pharmaceutical plan floor operations	Pharmazeutische Industrie	Pharmacology & Pharmacy	0	0	66	11A	1399-1403	USA	Industry

Part II – Content Information (Based on article numbers given in Part I and symbols given at the end of the table)

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
1	+	+	+	1	5	-	+	2	23	-	6	-	1	8, 3, 10, 2, 1, 6, 21	+
2	+	-	-	1	-	1	-	-	24	22	-	-	-	-	-
3	+	+	+	3	1	1	+	2, 9, 10	2, 13, 11, 21, 9, 18, 27, 23, 22, 7	-	-	-	-	3, 12, 6, 22	-
4	+	-	+	1	1	2	-	1	10, 7, 3, 15, 16, 17	-	-	-	1, 2	10	-
5	+	-	-	2	1	-	-	1	-	-	-	-	1, 3	-	-
6	+	-	+	1	1	-	-	-	2, 16, 4	-	-	-	1	10, 3	-
7	+	-	+	2	1	-	+	2	16	-	-	-	1	-	-
8	+	-	-	2	1	-	-	1	-	8, 9	-	-	3	-	-
9	+	-	+	1	-	-	+	-	-	-	-	-	1	6, 4, 2, 12, 8, 6	-
10	+	-	+	3	1	-	-	-	-	-	-	-	-	6, 20, 13, 3	+
11	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12	+	-	-	2	1	-	-	-	-	-	-	12	3	1	-
13	+	-	+	3	3	-	+	1, 2	1, 2, 13, 25, 11, 26, 27	2	11	-	3	0	-
14	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
15	+	-	+	2	2	1	-	1	-	-	-	-	3, 4	-	-
16	+	-	+	1	1	1	-	1, 5	-	-	-	-	1, 4	-	-
17	+	-	+	2	1	-	-	-	-	-	-	-	2	-	+
18	+	-	+	1	-	-	-	-	-	-	-	-	3	-	-
19	+	-	+	1	-	-	-	-	13, 20, 6, 3, 4, 11, 19	12	-	-	1, 2, 3, 4, 5	-	-
20	+	-	+	1	-	3	-	-	-	26	-	-	2, 4	-	+
21	+	-	+	1	-	-	-	-	7	-	-	-	-	3	+
22	+	-	+	1	8	1	+	1	-	-	-	23	1, 4	3	+
23	+	-	+	2	8	-	-	-	10, 2, 11, 26, 8	-	-	20	1, 4	-	+
24	+	-	+	1	1	3	+	1	1, 4, 3, 7, 2	-	-	-	1, 2	-	-
25	+	+	-	1	-	-	-	-	-	-	-	-	-	-	-
26	+	+	+	2	1	-	+	1, 2, 5	-	-	-	-	1, 3	5d, 12a, 8	-
27	+	+	+	3	1	3	+	1	2, 8, 6, 11, 12, 4	-	-	1, 5	1, 2, 3	3, 8	-

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
28	+	-	+	1	-	1	+	1, 2	-	-	-	-	-	-	-
29	+	-	+	2	1	1	-	1, 7	16	-	-	6, 7, 8	1	-	-
30	+	-	+	1	-	-	-	-	17, 18, 4, 3, 19, 20	-	-	-	-	-	-
31	+	-	+	1	3	-	-	3, 8	10	14, 13, 26	-	-	-	3	+
32	+	-	+	2	3	3	+	-	11, 2, 9, 26, 10, 31, 12	-	-	-	1, 2	-	-
33	+	-	-	2	3	-	-	-	-	-	-	-	-	-	-
34	+	-	-	2	3	-	-	-	22	-	-	-	1	3, 17, 3	+
35	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
36	+	-	+	2	3	-	-	-	2	10	-	9, 10	1, 2, 3	-	+
37	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
38	+	-	+	3	-	3	+	1	7, 4, 2, 23, 18	-	-	11, 7	1	10	-
39	+	-	+	3	3	1	+	1	-	11	-	4	3	-	-
40	+	-	+	2	9	1	-	-	-	-	-	-	2	5, 10, 22, 7, 8	-
41	+	-	-	1	-	-	-	-	-	-	-	-	-	-	-
42	+	-	+	2	1	-	+	1	28	-	-	-	1, 2	-	-
43	+	-	+	1	-	-	-	1	2, 10, 16	-	-	-	-	-	-
44	+	-	+	1	-	-	-	-	1, 29, 13	-	-	13	-	-	-
45	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
46	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
47	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
48	+	-	+	1	-	3	+	-	2, 13, 6, 8, 7, 3, 9	-	-	16, 17, 18	1	-	-
49	+	+	+	2	9	-	+	-	-	-	-	-	2	26d, 5a, 1a, 19a, 31d	-
50	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
51	+	-	+	1	1	1	-	2, 5	-	26, 3	-	-	-	6	-
52	+	-	+	2	1	3	+	1	2, 19, 4, 6, 26, 13, 18	-	-	-	2	-	+
53	+	-	+	1	-	2	-	-	11, 23	-	2, 14, 15	-	-	-	-
54	+	+	+	2	4	-	+	-	-	-	-	-	4	4m, 33i, 34a	-
55	+	-	+	2	4	-	-	-	-	-	-	-	-	-	_

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
56	+	-	+	1	-	-	-	-	22	-	-	-	-	-	-
57	+	-	+	1	-	-	-	-	22	-	-	-	-	-	-
58	+	-	+	2	3	-	+	2, 3	1, 13, 22, 3, 7	-	-	1, 10	1, 4	3	-
59	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60	+	-	+	1	-	1	+	-	11	-	-	-	1, 3	5m, 4m, 10a, 11a, 3i, 4c	-
61	+	-	+	2	1	-	-	1, 5	28, 2, 11, 13	25	-	20	3	5, 2, 1	-
62	+	-	+	2	3	2	+	-	-	-	-	-	2, 3	1,4, 6, 10, 2, 15	-
63	+	+	+	1	-	2	-	-	9	7	2, 3, 4, 5	-	-	-	-
64	+	-	+	1	2	3	+	1	1, 2, 28	10	-	-	1	26d, 32d, 6m, 12m, 19m, 8m, 4m, 1m, 2a, 32a, 3a, 5a, 21a, 9a, 8i, 5i, 9i, 6c, 5c	-
65	+	-	+	1	-	2	+	-	4, 9	-	-	-	1	5m, 8	-
66	+	-	+	2	2	2	+	2, 5	10, 26, 29, 20, 2, 11	-	-	-	1, 3	12, 9, 5, 2, 8, 22, 6	-
67	+	+	-	2	3	-	+	-	-	-	-	-	1	5, 3, 17	-
68	+	-	+	1	-	1	-	1	-	-	-	-	-	6	-
69	+	+	-	2	1	-	-	-	-	-	-	-	-	9	-
70	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
71	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
72	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
73	+	-	-	2	3	-	-	-	-	-	-	-	-	-	-
74	+	-	+	1	1	2	-	1, 2, 3, 6	1, 2	-	4	-	1	-	-
75	+	+	-	2	3	-	-	-	-	-	-	-	2, 3	-	-
76	+	+	+	2	2	1	+	-	-	-	-	-	3	5a, 4c, 6c	-
77	+	-	+	1	-	3	-	2, 3, 10, 5, 8	1, 2, 19, 4, 11, 30, 26, 5, 10, 16, 13, 3, 18	-	-	1, 7, 4, 23	1	3, 8, 13	+
78	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
79	+	+	+	2	2	2	-	-	-	-	-	-	3	-	-
80	+	+	+	2	2	2	+	-	-	-	-	15	3	2	-
81	+	-	+	1	-	-	-	1	1, 13, 25, 11, 20, 2, 3, 7, 4, 23, 26	-	-	3, 1	2	1	-
82	+	-	+	1	-	-	+	7	22, 26, 5, 8	-	8	10	-	-	-
83	+	-	+	1	1	1	+	2, 3, 5, 6	11, 16, 29, 2, 9, 1, 13	34	-	-	1	12, 8, 6, 1, 2, 21, 3, 12, 4, 9, 27, 5, 25	-

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
84	+	+	-	2	1	-	-	-	-	-	-	-	-	-	+
85	+	-	+	1	-	-	-	-	-	2, 26	-	-	-	-	-
86	+	-	+	1	-	-	+	1, 12	26	24	-	-	-	-	-
87	+	+	+	2	1	1	+	-	-	-	-	-	1, 3	5, 7, 8, 1, 25, 3	-
88	+	+	+	1	6	-	+	1, 2, 3, 6, 8	2, 27	-	15	-	2, 4	3, 6, 27, 38	+
89	+	-	+	2	4	-	-	1	3	-	-	-	-	4, 6	-
90	+	-	+	1	-	2	+	-	2, 9, 21	10	-	1, 2	-	2, 8, 12, 3	-
91	+	-	+	1	3	3	-	-	2, 13	-	-	-	-	1, 6, 2, 16	-
92	+	+	+	2	1	1	+	-	-	-	-	-	3	8, 7, 5, 4, 6, 2, 25, 3, 1	-
93	+	-	+	1	2	-	+	1	7	-	-	-	-	-	-
94	+	-	+	1	-	2	-	-	1, 2, 3, 9, 10, 11, 13, 19, 4	-	-	-	1, 2, 3	5	-
95	+	-	+	2	3	-	+	-	-	-	-	-	3	10, 11, 3, 6, 4, 5, 12, 2, 27	-
96	+	-	+	1	-	1	+	-	15, 21	13, 14	8	6	-	3, 2, 4, 5, 23, 22, 24, 6	+
97	+	+	-	2	1	-	-	1	-	-	-	-	-	-	-
98	+	+	+	2	8	-	-	-	1, 2, 3	13	-	25, 17	-	20, 24, 3	+
99	+	+	+	2	5	-	-	-	-	-	-	-	-	27, 39, 9, 15	-
100	+	+	+	1	6	-	-	-	24, 5	-	1, 10, 17, 4	-	-	6, 8, 17, 14, 36	-
101	+	-	+	2	3	1	+	-	-	-	-	-	-	26d, 7d, 27a, 9a	-
102	+	+	+	2	2	2	+	3	23, 26	20	-	-	1	12m, 4a, 8a, 2a	-
103	+	+	+	3	1	3	-	-	30	1, 2	-	-	-	4, 6	-
104	+	+	+	2	1	2	+	-	2, 14, 3	-	-	-	1	5d, 12m, 15m, 9a, 27a, 9i, 6i, 15i, 6c	-
105	+	+	+	1	6	1	+	2	2, 3, 4, 8, 9, 10, 6, 7, 26, 5	-	1	10	1	-	+
106	+	-	-	3	2	-	-	1	-	-	-	-	-	-	-
107	+	+	-	3	2	1	-	3	-	-	-	-	1	1	-
108	+	-	+	3	11	3	+	-	4, 2, 7, 11, 13, 10, 26, 8, 6, 16, 3	-	-	19	3	-	-
109	+	+	-	2	1	-	-	-	21	-	-	-	-	12, 27	-
110	+	-	+	2	2	-	-	-	-	-	-	3, 4	-	-	-
111	+	+	-	3	1	-	-	-	29	-	-	-	-	22, 6, 3, 5, 12	-

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
112	+	+	+	2	1	-	+	4	-	-	-	-	3	28m, 3a, 18i, 13c, 38a	+
113	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
114	+	+	+	1	-	2	+	-	10, 26, 20, 6, 23	-	-	-	-	32, 26, 20, 8, 12, 6, 4, 2, 1, 27, 13, 3, 29, 38	-
115	+	-	+	2	4	-	+	-	1, 2	-	-	-	3	5, 6, 12	-
116	+	-	-	2	1	-	-	-	-	-	-	-	-	13, 3, 9, 27, 28	+
117	+	+	-	1	-	-	-	-	-	-	-	-	-	4, 9, 13	-
118	+	+	-	2	1	-	-	-	-	-	-	-	-	-	+
119	+	+	-	2	1	-	+	-	-	-	-	-	-	3, 38	-
120	+	-	+	1	-	3	+	-	-	-	-	-	-	-	-
121	+	-	+	2	3	1	+	-	-	-	-	-	3	5d, 12m, 10m, 8m, 4a, 3i, 13i, 6c, 2m, 1i, 12c	+
122	+	+	+	2	1	-	+	-	-	-	-	-	3	6m, 12m, 4a, 3i, 6c, 27i	-
123	+	-	-	1	6	-	-	-	3	-	-	-	-	6	-
124	+	-	-	1	1	-	-	-	-	-	-	12	-	12, 25, 4	-
125	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
126	+	+	+	2	4	1	+	2	12, 13	15	-	-	2, 5	5m, 7m, 8a, 27a,	-
127	+	+	+	1	-	-	+	-	2, 4, 11, 6, 7, 13, 16, 24, 10, 18, 9, 5, 26	-	16, 4	-	2, 1	3, 22, 12, 20, 13, 9, 29	+
128	+	+	+	1	-	3	+	2	2, 18, 14, 13, 11, 24, 1, 16, 3, 7, 4, 6, 8	-	-	24	-	1m, 2m, 4m, 8a, 25a, 3a, 3i	-
129	+	+	-	1	2	-	-	1	-	-	-	-	-	-	-
130	+	-	+	2	2	1	-	-	-	-	-	-	3	4, 5, 2, 1	-
131	+	-	+	2	2	1	+	-	-	-	-	-	3, 1	5, 7, 8, 6, 9	-
132	+	+	+	1	-	2	+	1, 2, 3, 5, 8	16, 2, 20	5	-	-	-	13, 3, 20	+
133	+	+	+	1	2	1	+	-	3	-	-	2, 1, 10, 6	4	2, 5, 17	+
134	+	-	+	1	-	2	-	2	2, 3, 4, 23	-	-	-	1	-	-
135	+	-	+	2	5	1	+	3, 6	-	-	-	-	3	1, 2, 6, 20, 4, 5, 8	-
136	+	+	+	3	1	-	+	-	-	-	-	-	1, 2, 4	4	-
137	+	+	-	3	1	-	+	3	21	-	-	-	-	12m, 4a, 3, 27, 6	-
138	+	+	+	1	-	2	+	-	4, 7, 1, 6	12	-	22	-	-	-
139	+	-	+	1	-	3	-	2, 8	1, 6, 19, 3, 29, 10, 31, 11	-	-	-	1	4, 6	-

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
140	+	+	+	2	4, 10	2	+	2, 3, 6	20, 9,1, 11, 6, 2	-	-	-	1	5, 20, 1, 21, 32, 3, 2, 5, 8, 3, 22, 10, 26	+
141	+	+	-	2	2	1	-	9	-	3	-	-	-	-	-
142	+	-	+	3	3	1	+	7	21	-	-	-	1, 3	5m, 12m, 3i, 6c, 1, 9, 17, 18, 19	-
143	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
144	+	-	+	2	9	1	+	-	-	-	-	-	1	5m, 6c	-
145	+	+	+	1	-	-	+	-	2, 11, 31, 7, 3, 8, 19, 24, 6	-	1	-	1	5, 7, 12, 4, 8, 25, 3, 6	-
146	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
147	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
148	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
149	+	+	-	1	2	1	-	-	16	-	-	-	-	8, 31	+
150	+	+	-	2	3	-	-	-	-	-	-	-	1	13, 37	-
151	+	+	-	2	1	-	+	3	5, 21, 26	-	-	-	2, 1	12, 27, 6	-
152	+	+	-	1	1	-	-	-	-	-	-	-	-	9	-
153	+	-	-	1	6	-	+	4	2	-	-	-	-	3	+
154	+	+	+	2	2	2	+	-	-	-	-	15	2	2	-
155	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
156	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
157	+	-	+	3	-	-	-	-	-	15	9, 10	-	1, 2	17	-
158	+	+	+	2	1	-	+	4	30	-	-	-	3	3m, 13v, 28m, 38a	+
159	+	+	+	2	2	-	+	-	8, 1	-	-	-	-	11a, 6a, 35m	-
160	+	+	+	2	1	-	+	-	-	-	-	1, 2	-	8, 12, 13, 3, 6, 4	+
161	+	+	+	2	1	1	+	-	-	-	-	1, 2, 3	-	1d, 8d, 5d, 12m, 3di,	-
162	+	+	-	1	1	-	-	4, 13	-	32	-	-	2	-	-
163	+	-	-	1	5	-	+	-	-	-	-	-	-	-	-
164	+	+	+	3	1	-	-	-	-	-	-	-	-	38, 9	-
165	+	+	+	2	1	-	+	1, 2, 5, 7, 12	22, 1	-	-	-	2, 4, 5	26d, 6m, 1m, 4m, 5m, 12m, 8m, 7m, 10m, 2m, 9a, 3i, 38i	-
166	+	-	-	1	1	-	-	-	-	-	-	-	-	6	-
167	+	+	-	3	1	-	+	-	-	-	-	-	-	9, 3, 19, 6, 38	-

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
168	+	-	-	2	1	-	+	-	16	-	-	-	-	-	+
169	+	+	+	2	12	2	+	-	-	-	-	-	-	14	-
170	+	+	-	1	1	-	-	-	-	-	-	-	-	-	+
171	+	-	+	2	1	-	+	-	-	-	-	-	-	4m, 2a, 9i, 4i, 6c	-
172	+	-	-	1	1	-	-	4	-	-	-	-	-	3, 8, 6, 30, 13, 4, 31	+
173	+	+	+	3	12	-	-	4	-	-	12	-	3	4, 18	-
174	+	+	+	2	1	-	+	-	-	-	-	-	-	6, 3, 17, 28, 29	+
175	+	+	+	3	1, 2	1	+	2, 3, 5, 6, 9, 10	2, 4, 13, 3	16, 2, 17, 29, 3, 14, 18, 19	-	14	1, 2, 3, 4	12, 6, 3, 8, 4	-
176	+	-	+	2	3	1	+	-	-	-	-	-	3	6	-
177	+	-	+	2	2	1	+	-	-	-	-	21	1, 3	2m, 6c, 5	-
178	+	-	-	2	1	-	-	-	-	-	-	-	3	6, 3, 17, 27, 38	-
179	+	+	+	2	2	-	+	-	1	-	-	-	3	4m, 5m, 7m, 8a, 25a, 6, 22	-
180	+	+	+	2	7	-	+	-	-	-	-	-	-	14, 17, 30, 12, 6, 8, 29	+
181	+	+	+	1	-	2	+	4, 11, 13	9, 10, 26, 3	-	-	-	-	10d, 1d, 20d, 11d, 8a, 5a, 27a, 6a, 25a, 3i, 12c, 6c, 4c, 38	-
182	+	+	+	2	7	-	+	-	-	-	-	-	-	10a, 19, 13design, 19design, 29design, 6v	+
183	+	+	+	3	10	2	+	1	10, 26, 8, 6, 16, 22	-	12	-	2, 4	20d, 12m, 4m, 1m, 6m, 5m, 1a, 2a, 21a, 5a, 9a, 3i, 8a, 6c	-
184	+	-	+	2	4	3	+	1, 3, 6	3, 27, 31, 9, 2, 4, 7, 11, 19, 8, 1	-	-	16	3, 2, 1	21, 17i, 20d, 1d, 8d, 26d, 5m, 2m, 12m, 3a, 4a, 9a, 27a, 6i, 9i, 3i, 13i, 37i, 6c, 8c	+
185	+	+	-	3	1	-	-	-	-	-	-	-	-	4, 27, 37	+
186	+	+	+	2	1	3	+	2	10, 2, 7, 3, 11, 20, 8	-	-	-	1, 5	11, 7, 6, 25a, 5m, 26m, 1m, 9m, 12m, 2m, 15m, 27i, 3i, 4c, 38i	-
187	+	+	+	3	1, 5, 7	-	+	3, 6	23, 11, 15, 4, 19	2	15	-	2	3, 12, 20, 8, 5, 4, 9, 25, 27, 6, 15, 21, 13, 26, 1, 32	+
188	+	+	-	1	6	1	+	-	-	1, 4, 5, 6	5	-	-	12, 3, 4, 29	+
189	+	+	+	3	7	1	-	-	-	-	-	-	4	38, 34, 4, 13, 3	-
190	+	+	-	1	-	-	-	1, 2	-	-	-	-	-	13	-
191	+	+	-	2	1	-	-	-	-	-	-	-	-	3, 4, 13, 30, 38	-
192	+	+	-	1	1	-	-	4	-	-	-	-	-	-	+
193	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
194	+	-	-	1	3	-	-	6	-	-	-	-	-	35, 18	+
195	+	+	-	2	1	-	-	-	-	-	-	-	-	3, 28	+

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
196	+	+	+	2	1	3	-	4	30	-	-	-	-	3, 18, 13, 1, 34, 38, 28	+
197	+	+	+	1	-	2	+	4, 11	9, 10, 26	30, 31	-	-	-	9, 5, 2, 6, 25	-
198	+	+	-	2	1	-	-	-	-	-	-	-	-	6, 2, 3, 20	-
199	+	+	+	2	3	3	+	-	-	-	-	-	-	12, 5, 8, 27, 6, 3, 26	-
200	+	+	+	2	1	-	+	1, 2	28, 2, 1, 6, 11	-	-	16, 17	1, 2, 3, 4	6, 4, 12, 3, 20, 8, 27, 9, 1, 2, 21, 5d, 12m, 4m, 1a, 2a, 3i, 6c, 8c	-
201	+	+	-	3	1	1	-	4	-	-	-	-	-	28, 13, 38, 3, 42	+
202	+	-	-	3	1	-	-	4	-	-	-	-	-	18, 4, 3	+
203	+	+	+	2	1	3	+	4	3, 31, 26, 30, 2, 11, 1, 13, 8, 14, 10	33	5	-	1, 3	5m, 2m, 7m, 4m, 1a, 3i, 10a, 4i, 6c, 5d, 20m, 1m, 12m, 27a, 9a, 2i, 15i, 9i, 38	-
204	+	+	+	2	1	3	+	-	29	-	-	-	3	5d, 20m, 2m, 4m, 6m, 3a, 14i, 27i, 4c, 6c, 17, 37, 28, 38a	-
205	+	+	+	1	1, 2, 7, 8	3	+	1, 2, 3, 5	1, 2, 3, 27, 7, 8, 14, 11, 16, 13, 4	26, 7	2	-	1, 3, 4	6, 4, 12, 3, 20, 8, 9, 5, 13, 10	+
206	+	+	-	2	1	-	-	-	-	-	-	-	-	20, 25	+
207	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
208	+	+	+	2	1	-	+	1, 2, 5, 7, 12	22, 1	-	-	-	2, 4, 5	26d, 6m, 1m, 4m, 5m, 12m, 8m, 7m, 10m, 2m, 9a, 3i, 38i	-
209	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
210	+	+	-	2	4	-	-	-	-	-	-	-	-	6, 17	-
211	+	+	+	3	2	2	+	1, 2, 3, 7	11, 5	7	20, 10	-	1, 2, 4	13i, 6c, 3i, 5d, 20m, 11m, 12m, 6m, 4m, 13m, 8a, 9a, 27a, 13a, 34i, 18i, 38	+
212	+	+	-	2	5	-	-	-	-	-	-	-	-	-	-
213	+	+	-	1	-	-	-	4, 11	-	-	-	-	-	9, 25, 2, 5, 6, 15, 24, 17	-
214	+	-	-	1	1, 2	-	+	-	-	-	-	-	-	-	-
215	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
216	+	+	-	1	2	-	-	1, 2, 3	2, 13, 10, 11, 23, 16	-	13	-	-	2, 21, 1, 6, 32, 12, 22	-
217	+	+	-	1	1	-	-	4	-	-	-	-	-	38	+
218	+	+	+	1	-	3	+	9	30, 11, 3, 23, 2, 19	-	-	-	-	-	-
219	+	+	+	1	-	2	+	3, 10	2, 10, 27, 9, 11, 3, 26, 18, 29	7, 27, 19, 13, 28, 12, 14	18, 19	-	-	20, 8, 3, 6	+
220	+	-	+	1	2	1	-	2	29, 22	-	-	-	-	-	-
221	+	+	-	1	5	-	-	-	-	-	-	-	-	-	-
222	+	+	+	1	1	-	+	9	30, 11	23	-	-	-	8, 2, 6	-
223	+	+	-	1	2	-	-	-	-	20, 21	-	-	-	-	-

No	Full text	Keywords	Relevance	Type	Sector	Definition	DMAIC	Other Init.	Success Factors	Criticism	Future	Challenges	Metrics	Tools	DFSS
224	+	-	-	1	-	-	-	-	1	12	7	-	-	-	-
225	+	-	-	1	2	1	-	1	-	-	-	-	-	-	-
226	+	+	-	2	3	-	+	-	-	-	-	-	3	3	-
227	+	+	+	1	-	-	+	2, 3	3, 13, 6, 2, 24	13	-	-	-	2, 3, 5, 10, 1, 6	-
228	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
229	+	+	+	2	1	-	+	-	-	-	-	-	1, 3	5d, 7m, 8m, 4m, 4i	-
230	+	+	+	2	2	1	+	-	-	-	-	-	3	4d, 3m, 13a, 18a	-
231	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
232	+	+	-	2	1	-	-	-	-	-	-	-	4	21	-
233	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
234	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
235	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
236	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
237	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
238	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
239	+	-	+	2	1	-	-	-	3	-	-	-	-	30, 4	+
240	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
241	-	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
242	+	-	+	1	1	-	-	-	16	-	-	-	-	4, 6	-
243	+	+	+	2	1	-	+	-	-	-	-	-	3, 1	5d, 7m, 8m, 4m, 4i, 12c, 6c	-
244	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
245	-	+	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

The numbers given in columns symbolize the followings:

Number	Tools	Critics	Success factor	Challenges	Future
-	None	None	None	None	None
1	Pareto chart	Standard goal for all processes	Cultural change	Budget constraints	More user-robust tools
2	Fishbone diagram	Only an advertisement tool	Management commitment	Time constraints	Evolution from defect/cost reduction to value creation
3	Design of experiments	Cumbersome and unfathomable	Clear performance metrics & integration with business strategy	Personnel viewing data collection as extra work	More applications in Far East
4	Process capability analysis	Too much emphasis on quantifying payoffs	Selecting and training right people	Reluctance of management to actively engage	Less applications in manufacturing, more in service sector
5	Process mapping	Expensive	Data quality	Lack of communication between experts and workforce	Engagement of academic institutions in six sigma education
6	Statistical process control	Too much focus on yearly performance reviews and forced ranking system	Good communication and common language	Differing penetration of six sigma among different functions	More idea generation and simulation tools
7	Cause-and-effect matrix	Presented as a anacea for all business ills	Project selection	Resistance from middle managers	Effects of process improvement on workforce to be studied
8	FMEA	Hard to apply accross business functions	System for monitoring, measuring and reporting performance	suppliers not willing to be involved in efforts	E-manufacturing and e-business effects on six sigma
9	Hypthesis testing & confidence intervals	SPC oriented, no wide perspective	Quantified financial impact	Unsatisfactory results of customer satisfaction	More non-linear methods to be employed
10	Benchmarking	Not fast enough	Customer focus	Hard data collection / lack of available data	Further use of neural networks and fuzzy logic
11	Gap analysis	Necessitates a different kind of culture	Training	Lack of communication between experts and management	More periodical reviews
12	Measurement system analysis	Doesn't consider the effects of quality of working life	Stable performance and quality improvement culture	Lack of raw material quality from suppliers	Advances in software, hardware and network technologies to bring easier and cheaper implementations
13	Queueing & simulation	Doesn't allow for random research and invention, process map dependent	Commitment, involvement, empowerment and satisfaction of team members	Lack of profound knowledge of processes by functional managers	Web based audit systems for better decision-making
14	Fuzzy logic	Internally focused	Six sigma infrastructure	Lack of integration with other initiatives and business practices	Cheaper-to-train white belts
15	Box plot	Confusing name	Viewing six sigma as a process rather than a tool	People don't believe performance can be further improved	Web-based training programs
16	FAST diagrams	No focus on inventory management	Involving suppliers / customers in six sigma process	Lack of management commitment	More applications in small and medium sized enterprises
17	Artificial neural networks & AI	Quality should be integrated into design	Knowing the best practices in the industry	Resistance to culture change	New tools for design
18	Mathematical programming	Defect and opportunity definitions not clear	Not limiting the projects with manufacturing	Giving six sigma program authority	Systemic perspective for multiple CTQs

Number	Tools	Critics	Success factor	Challenges	Future
19	Time series analysis	Claims all defects to be equal	Rewards	Lack of personnel to devote full time	Scenario-based planning
20	QFD	Considers doctors as economic actors	Cross functional teams	Preconditioning by notions of what has happened in the past	Integration of OR/MS tools
21	Scatter diagrams	Too much emphasis on measurement, less emphasis on change	Good measurement system	Hawthorne effect	
22	Surveys	Diminishing returns for gains	Statistical software and IT infrastructure	Poor project selection	
23	Pugh matrix	Reduces performance for problems with obvious solutions	Training going together with real projects	Suboptimization	
24	TRIZ	No focus on policies and management theory	Systemic and innovative thinking	Failure to provide six sigma infrastructure	
25	Multivari analysis	Creates elite BBs disconnected from the shop floor	Deployment plan	"Not suitable for us"	
26	SIPOC diagram	No original tools introduced	Data and fact driven management		
27	ANOVA	May progress well in wrong direction	Project-focused approach		
28	Finite element analysis	No focus on customization	Implementing six sigma in a lean environment of after a lean project		
29	CART & MARS	No focus on knowledge economy/society	Profound knowledge of processes		
30	Design for manufacturability / assembly	Not enough emphasis on feedforward and feedback	Goal setting		
31	Fault tree analysis	Tools not placed in a strategy	Management objectives deployable to the shop floor		
32	Affinity diagrams	Very hard goal			
33	Analytic hierarchy process	Lack of theoretical underpinning			
34	Sensitivity analysis	No standards in certification			
35	SWOT analysis				
36	Data mining				
37	Genetic algorithms				
38	Response surface methodology				
39	Contingency table analysis				

Number	Other Initiatives	Sector/Field	Type	Definition	Metrics
-	None	No specific sector	-	None	None
1	Lean management	Manufacturing	Conceptual	Statistical	Monetary
2	Total quality management	Healthcare	Case Study	Business	Reduction in variation - not quantitative
3	ISO/QS	Chemical	Both	Both	Reduction in variation - quantitative
4	Taguchi - Robust design methods	Other service sectors			Reduction in yield time
5	Kaizen	Software			Others
6	Malcolm Baldridge National Quality Awards criteria	Statistics			
7	Enterprise resource planning	Finance			
8	Business process reengineering	R&D			
9	Zero defects	Environment			
10	Quality circles	IT			
11	Shainin system	Construction			
12	Theory of constraints	Supply chain management			
13	Statistical process control				