An Empirical Study Into the Limitations and Emerging Trends of Six Sigma: Findings From a Global Survey

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Abstract—The purpose of this article is to identify and evaluate the limitations and emerging trends of Six Sigma from the perspectives of Six Sigma experts. The authors developed an online global survey and deployed the survey to 1250 Six Sigma experts of which 307 experts responded. The article finds integration of Six Sigma with Big Data to be the topmost emerging trend as Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises would be very beneficial. The manufacturing sector experts nominated the topmost emerging trend as Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises to be very challenging and will be rewarding if implemented properly. In the service sector, the topmost emerging trend was the integration of Six Sigma with Big Data. However, public sector experts felt variance reduction should not be the only goal of Six Sigma implementation. The that master black belts perceived Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises would be advantageous, whereas Black and Green Belts perceived Integration of Six Sigma with Big Data to be topmost emerging trend.

Index Terms—Emerging trends, empirical study, limitations, Six Sigma.

I. INTRODUCTION

Six Sigma is employed by many organizations as a business strategy for the purpose of business process improvement since its origins in the mid-1980s [1]–[3]. Six Sigma implementation has led organizations to save millions of dollars as a result of its implementation. Prominent organizations, including Allied Signal (also known as HoneyWell), General Electric, Caterpillar, Cummins,ABB, Johnson and Johnson, American Express, and Bank of America attribute bottom-line savings to Six Sigma initiatives [4]–[6]. One of the most comprehensive definitions of Six Sigma, taking into account both the "what" and the "how" of the theory, was proposed by Schroeder et al. [7], who defined Six Sigma as “an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives.” Six Sigma is also understood as a change management philosophy, which can trigger a positive effect within organizations [7]–[9].

The majority of studies primarily agree on the positive effects of Six Sigma, such as cost savings and defect reduction [10]–[14]. However, at the same time, it is estimated that 62% of Six Sigma initiatives have failed [15]. There are several examples of failures implementing Six Sigma [16], [17]. Six Sigma like any other quality improvement initiatives starts off well, but, as time progresses, it may fail to have a lasting impact. As a result, the motivation drops and organizations fall back into the same old habits [18]. A national survey in the healthcare companies indicates that 54% of the companies do not really intend to implement Six Sigma [19]. Additionally, there are studies that advocate that intensive efficiency orientation will eventually damage long-term variables, such as organizational growth [20], [21]. The limitations of Six Sigma from previous studies are elucidated in Table I. In order to address these limitations of Six Sigma, it is necessary to identify the Six Sigma limitations from the Six Sigma expert’s perspectives.

Furthermore, the modern organizations are changing due to the fourth industrial revolution. The Big Data generated from modern manufacturing process have to be used in a proper manner for a meaningful analysis [4]. Besides, environmental aspects should also be considered in Six Sigma [22]. In addition, the success of Six Sigma in small- and medium-sized enterprises (SMEs) and microenterprises is also a challenge [23]. As Six Sigma has been evolving over the past 30 years, the authors felt that it is important to understand the emerging trends of this powerful business strategy and the future directions so that academics can address them by working closely with professionals in industry. The emerging trends of Six Sigma from previous studies are elucidated in Table I. Therefore, an empirical evaluation of these emerging trends of Six Sigma from Six Sigma expert’s perspectives would help to understand the areas to be focused on for future research. Previous studies have described Six Sigma criticisms [2]. This study contributes to this research, running an empirical investigation that evaluates the limitations and emerging trends through Six Sigma experts’ knowledge from around the world. Six Sigma implementation differs in manufacturing, services, and public services [2], and therefore
it would be interesting to analyze the limitations and emerging trends from the perspectives of Six Sigma experts working in these areas. Furthermore, Six Sigma is well implemented in continents, such as North America and Europe; however, its implementation in Africa has been scanty [24]. Therefore, the analysis of limitations and trends from Six Sigma experts across the continents will add diverse viewpoints. Finally, knowledge and responsibility of Six Sigma experts differ according to different Six Sigma belts [25] and also to the years of Six Sigma experience [24]; therefore, the limitations and emerging trends need to be explored from the perspective of different Six Sigma experts. In a nutshell, the purposes of this article are as follows. 1) To identify the top five limitations and emerging trends of Six Sigma from the viewpoint of Six Sigma experts from different continents, belt-wise, years of experience, and sectors (manufacturing, service, and public sector).

The rationale for treating the same together is because limitations depict inherent challenges within the Six Sigma methodology and emerging trends depict the future roadmap of Six Sigma. Combined analysis will depict significance of position of limitations with respect emerging trends so that practitioners and researchers can use the relative understanding to expand the Six Sigma methodology.

2) To test Six Sigma experts’ perceptual differences in limitations and emerging trends of Six Sigma as according to belt-wise and years of experience in Six Sigma.

This is the first article to empirically evaluate the limitations and emerging trends of Six Sigma through a global survey of Six Sigma experts, including different contextual aspects in the analyses. There is a lack of studies of this magnitude, which offer a more complete diagnosis of the reality of Six Sigma implementation. This article will help the practitioners to understand and develop solutions to overcome the limitations of Six Sigma implementation and future challenges within the organizations. The rest of this article is organized as follows. Section II presents a detailed literature review relating to the top ten limitations and the five emerging trends of Six Sigma. Section III describes the research methodology employed in this study. Section IV presents an in-depth analysis of the data and a discussion on the major research findings. Finally, Section V concludes this article.

II. LITERATURE REVIEW

Through a systematic literature review, Sony et al. [2] identified the limitations of Six Sigma and emerging Six Sigma trends, which are discussed below.

A. Ten Limitations of Six Sigma

The first limitation of Six Sigma is identified as high failure rate. Glasgow et al. [26] and Albliwi et al. [15] reported that over 60% of Six Sigma initiatives in organizations failed to deliver the desired results. Interestingly, the benefits resulted in the first two to three years, but the desired results were not realized. One of the main reasons attributed to Six Sigma failure was a drop in enthusiasm, resulting in many organizations reverting to former work practices [18]. Studies indicate that approximately 60% of all corporate Six Sigma initiatives fail [16], [17], [27], [28]. As a result, Six Sigma initiative failures cost many organizations a considerable amount of money. It may be challenging to identify where failures occurred as the levels at which failures can occur may vary including individual, team, project, or organizational. Such factors for high failure rate should be studied in greater detail in order to understand the failure mechanism.

The second limitation concerns the high cost of Six Sigma implementation, especially during early implementation stages [29]. When implementing process improvement strategies, high start-up costs can often act as an unfavorable factor for organizations [30].

The third limitation associated with Six Sigma is identified as a negative impact on customer satisfaction if Six Sigma is not implemented properly [31]–[33]. Two major US corporations have abandoned their Six Sigma initiatives due to their negative impact on customer satisfaction [27], [31], [32]. However, studies also suggest that Six Sigma promotes customer satisfaction and innovation [33]–[38].

The fourth limitation identified suggests that inadequate Six Sigma implementation leads to a negative impact on employee satisfaction. One study has shown that varying levels of Six Sigma implementation results in differing levels of job satisfaction [39]. Another study also suggests that poor Six Sigma implementation can have a negative impact on employee morale and engagement [40], because of the structured methodology in its implementation.

The fifth limitation of Six Sigma indicates that the structured and disciplined nature of this type of problem-solving approach can stifle employee creativity and innovation [31], [32]. Six
Sigma’s structured sequence of steps and rigorous analytical method can also lead employees toward rigidity [17], [33]. This argument has led to two interesting viewpoints. The first viewpoint suggests that Six Sigma stifles employee’s innovation skills [17], [31], [32], and the second viewpoint suggests that Six Sigma fosters innovation [41], [42].

The sixth limitation of Six Sigma suggests that any benefits accruing from Six Sigma are low in relation to both the effort and the cost invested [43]. Studies contend that lower benefits accrue from Six Sigma initiatives, in comparison with the amount of effort invested (in terms of resources and time) [27], [43], [44]. However, studies also suggest that Six Sigma implementation has resulted in significant financial savings [25], [45], [46]. Furthermore, very few SMEs have reported that the ratio of investment to benefits resulting from their Six Sigma initiatives is low.

The seventh limitation revolves around the fundamental assumption of a 1.5 σ shift in the process mean for any long-term variability study in business processes. Ramberg [97] suggested that such an assumption is groundless and makes little sense from a practical perspective. Without σ shift, the process would have produced defects at a rate of two parts per billion [47], [48]. When the process mean shifts by 1.5 σ, the defect rate will increase from 2 parts per billion to 3.4 defects per million opportunities [49]. However, these assumptions do not hold true for nonmanufacturing processes, including billing, recruitment, admissions, customer complaints handling, and surgical processes in hospitals [1], [50], [51].

The eighth limitation of Six Sigma is an overarching criticism regarding what is novel in Six Sigma. Many researchers have depicted the fundamental differences of Six Sigma with many quality improvement initiatives of the past, including Total Quality Management (TQM) and Lean [5], [6], [25], [53]. Snee [6] provided a detailed commentary on the critical differences between Six Sigma and TQM. Six Sigma places an unprecedented emphasis on the financial savings to be generated and on the commitment of senior executives in organizations. The second distinguishing aspect is that a clear and specific infrastructure is required for the successful deployment of Six Sigma. The infrastructure includes champions at various levels of Master Black Belt, Black Belt, Green Belt, and Yellow Belt. Finally, Six Sigma is not just focused on the use of specific tools but rather on the integration of such tools in each phase of the problem-solving methodology.

The ninth limitation of Six Sigma concerns an understanding of the nonstandardization and associated delivery method. Lauraeni and Antony [54] suggested that there are issues with curriculum nonstandardization and associated training delivery. Many trainers provide off-the-shelf training materials to service and other nonmanufacturing sectors. Furthermore, scant attention is paid to the customization of Six Sigma curriculum for SMEs and public sector organizations. A nonstandardized education system also facilitates the development of a variety of learning patterns and behaviors, which may be unfavorable to the successful implementation of Six Sigma and also to its future growth.

B. Emerging Trends in Six Sigma Research

The first emerging trend associated with Six Sigma is its integration with Big Data [4]. Few studies have explored the relationship between Six Sigma and Big Data. However, Big Data was used for identifying real-time defects and their root causes in processes [55]. They further propose “a novel approach for data-driven Quality Management in industry processes that enables a multidimensional analysis of the anomalies that can appear and their real-time detection in the running system.”

The second emerging trend and gap in Six Sigma research is integration of Six Sigma with Green initiatives. Green Six Sigma is associated with the assessment and reduction of the direct and ultimate environmental impact of all processes and products of an organization [22]. The integration of Green and Six Sigma concepts would create efficiencies and provide further opportunities to improve and sustain organizations’ environmental footprints. Moreover, the authors further argue that such an integrated approach could provide benefits, such as reduced cost, decreased consumption of raw materials, decreased wastewater, longer resource life (through reduced usage, reduced emissions, reduced energy consumption), and improved employee health and safety (due to less exposure to harmful chemicals).

The third trend of Six Sigma concerns the challenge of its integration with Industry 4.0 [56]. Industry 4.0 is a concept better known as the “Smart Factory” where machines are connected together as a collaborative community in order to collect, exchange, and analyze data systematically in a self-regulated manner [57], [58]. Six Sigma integration with Industry 4.0 has the potential to make a highly optimized ideal process flow defect-free with minimum wastage [59]. In the health service sector, the integration of Six Sigma with Industry 4.0 has resulted in improved quality of patient care as well as reduced operational costs [60].

The fourth emerging trend of Six Sigma is its applicability in SMEs, particularly in small- and microenterprises with less than ten employees [23]. Within SMEs, generally, there remains issues regarding the availability of talented staff in executing projects along with a consideration of budget and time constraints. The current literature gaps on Six Sigma’s applicability in SMEs includes questions, such as How many Green Belts and Yellow Belts are required for the successful deployment of lean six sigma (LSS) in an SME environment? What is the scope of Six Sigma projects in an SME environment? and What is the nature of Six Sigma curriculum most suited to SMEs? [61].

The fifth emerging trend of Six Sigma is its suitability as an initiative in public sector organizations. Many studies are published on Lean and its applications in various public sector.
contextual factors, such as healthcare and education [61]. However, studies that explore the impact of Six Sigma on local councils, higher education institutions, emergency services, municipalities, etc., should be further researched for its long-term suitability [37], [63].

C. Contextual Factors

Six Sigma challenges in nonmanufacturing sector are varied in nature. Some of the challenges in nonmanufacturing sector are service (nonproduction) focused environments struggle with metrics identification, creating a measurement of a process, dealing with customer variability, face difficulties with creating cultural change and creating Six Sigma leaders, and failure to capture the benefits of Six Sigma application [64]. In public sectors, the drive to look at public bodies and services has not only been caused by financial drivers, but equality of access to services, tackling unfairness, and inefficiencies have also been factors to consider; therefore, challenges of implementing Six Sigma are varied [63]. Therefore, it is pertinent to examine the differences of the limitations and emerging trends of Six Sigma in terms of manufacturing, services, and public sectors for any differences.

Furthermore, the national culture influences the effective implementation of Six Sigma [40]. The rapid growth of Six Sigma in US corporations compared with those in Europe is due to a better cultural fit, whereby US corporations are typically decentralized and formal [65], [66]. In addition, Six Sigma is well implemented in continents, such as North America and Europe; however, its implementation in Africa has been scanty [24]. Therefore, the limitation and emerging trends could be influenced by the continent where it is implemented and hence should be analyzed for any similarities and differences across the continents.

Finally, the knowledge, roles, and responsibilities of Six Sigma experts differ according to Six Sigma hierarchical belt system [25] and in terms of number of years of Six Sigma experience [24]. Therefore, the limitations and emerging trends could be influenced by the years of experience of Six Sigma experts/consultants and also the Six Sigma belts and hence should also be analyzed for any similarities and differences experienced across these clusters.

III. RESEARCH METHODOLOGY

The research questions driving this article are the following.

1) What are the top five limitations and emerging trends of Six Sigma from the viewpoint of Six Sigma experts from different continents, belt-wise, years of experience, and sectors?

2) Is there any difference in Six Sigma experts’ (continent-wise, belt-wise, number of years’ experience) perceptions on Six Sigma limitations and emerging trends?
3) Is there any difference in Six Sigma experts’ perceptions on the limitations and emerging trends of Six Sigma between manufacturing, service, and public sector?

To address the above-mentioned research questions, the authors utilized an online survey for data collection targeted at large manufacturing, service, and public sectors. This survey method is one of the most appropriate methods for this type of study, as it enables the collection of a large amount of information from respondents in a short period of time. The survey instrument developed for this article was divided into two sections, one to ascertain general information about the respondents, and the second section was dedicated to listing 15 limitations and emerging trends, which were identified through a systematic literature review [2].

In the second part of the survey, seven-point Likert-type scales were used to measure the responses to the questions regarding limitations/emerging trends. These scales provide adequate levels of discrimination among the choices presented to respondents. Potential respondent’s answers were measured with a seven-point scale, anchored at, for instance, 7 “strongly agree” and 1 “strongly disagree.” The scale was used in order to assist respondents to make an exclusive and decisive choice [67]. Each of the limitation/emerging trend was measured using a single item scale mainly because each of the limitation/emerging trend was unambiguous and concrete. Studies have shown that the single item scale performed, as well as a multiitem scale, when the construct was unambiguous and concrete [68], [69]. Additionally, as Six Sigma experts are busy professionals and unnecessary long questionnaire may not be attractive to them, the short nature of the questionnaire scaffolds respondents in answering the survey in a short period of time. A pilot study was conducted during the scale development process. The online survey protocol was first piloted with ten experts. Five were academics who have extensively published at least five Six Sigma articles and five were Six Sigma practitioners with high-level belts [master black belts (MBBs) and black belts (BBs)] and who have pursued a number of process improvement projects in their respective businesses [70]. The purpose of piloting the survey questionnaire was to validate it and ensure that the questions aligned with the research questions set by the researchers [71]. The comments and feedback from the pilot study were subsequently used to review the survey questions and make the questions more readable and relevant to the research. Most of the comments were positive, and hence the survey questionnaire was deemed suitable for research. The revised online survey link was sent out to 1250 subject-matter experts who are working in their respective organizations in roles such as MBBs, BBs or green belts (GBs) or Yellow Belts. The contacts were obtained through LinkedIn, and each of the respondent was contacted through email. The authors used three criteria in the selection of such subject matter expert. 1) All respondents should have a minimum of three years’ experience in their role as a process improvement specialist. 2) All respondents should have carried out a minimum of two process improvement projects and 3) have been involved in at least three process improvement projects as a team member. Setting such criteria will enable the authors to glean knowledge from a high caliber of experts from the survey participants, who are responsible for the execution of process-improvement-related projects in their respective organizations.

A total of 307 responses were collated over a 24-week period, yielding a response rate of 24.56%. Easterby-Smith et al. [72] argued that a 20% survey response rate is widely considered to be sufficient. The sample characteristics are given in Table II.

All the questionnaires were sent out to survey participants on the same day. In order to test for nonresponse bias, we conducted a time trend extrapolation test [73], [74] by comparing early and late respondents in different continent samples. Early
respondents were respondents who responded within first four weeks, and late respondents were those who responded in last four weeks during the 24-week period. Moreover, the authors have also utilized peer-reviewed articles for designing the questionnaire and send automatic reminders to some respondents in reducing nonresponse bias. Moreover, the authors have reassured all the participants well in advance that the data collected will be kept completely confidential. No significant differences were observed between early and late responses.

IV. RESEARCH FINDINGS AND DISCUSSIONS

The findings of this article were analyzed as follows:
1) limitations and emerging trends of Six Sigma continent-wise analysis;
2) limitations and emerging trends of Six Sigma sector-wise analysis;
3) limitations and emerging trends of Six Sigma belt-wise analysis;
4) limitations and emerging trends of Six Sigma experience-wise analysis.

A. Limitations and Emerging Trends of Six Sigma Continent-Wise

Experts from Africa, Asia, Europe, and North and South America continents participated in this research. The continent-wise top five limitations of Six Sigma are listed in Tables III–VII. For each question, the scores were summed for all responses. High sum indicates that most respondents have agreed to the particular limitation or emerging trend. The mean scores were used to rank the limitations [75].

Four out of five emerging trends of Six Sigma are also featured in the top five limitations and emerging trends in Asia. In Asia, it is perceived by experts that the limitation associated with variation reduction should not be the sole goal of Six Sigma featured in top five limitations. The perception of experts in relation to emerging trends suggests that Six Sigma experts in Asia are concerned with the integration of Six Sigma with Big Data, Industry 4.0, Green agenda, SMEs, and microenterprises rather than being concerned about other limitations.

In Europe, experts’ perceptions were focused on the emerging trends. However, all experts apart from experts in Asia recognized that Six Sigma’s implementation limitation may have a negative impact on employee satisfaction. Experts in Asia did not consider employee satisfaction to be an important criteria, and this may have been influenced by a large population and high unemployment rate [76], [77].

The emerging trend of integration of Six Sigma and Industry 4.0 did not feature in either Europe or North America. This may be explained partly because Industry 4.0 is so well researched and implemented in Europe and North America [78]–[80] compared with other continents. Therefore, Six Sigma experts may not have considered it as a top five emerging trend but rather as an implementation guideline. In other continents, Industry 4.0 is seen as an emerging trend because Industry 4.0 implementation is not as widespread, and therefore it is seen as an emerging trend.

In the continents of South America, Africa, and Asia, the emerging trend of integration of Six Sigma with Big Data, which is perceived to bring superior results to many organizations in the future, was rated in the top rank by the Six Sigma experts. Big Data poses many challenges and pitfalls in developing countries compared with developed countries [81]. Interestingly, Six Sigma experts perceived it as a challenge in developing continents as compared with developed continents, such as North America and Europe.

An important question that is also worth investigating is whether any significant differences arose in the perceptions of Six Sigma experts across the continents studied. For this analysis, the data were tested for normality. The Anderson–Darling test was conducted, and it was found that all the variables do not follow normal distribution. As the data were nonnormal, the Kruskal–Wallis test [82] was conducted to test whether there is significant difference in mean scores of responses in limitation/emerging trends across all continents. The Kruskal–Wallis test, a median test, can be considered as a backup method for analysis of variance (ANOVA) where the independent variable is categorical (three or more than three groups) but the dependent variable is not normally distributed. The null hypothesis is that these three-sample means are from the sample population, μ1 = μ2 = μ3 [83]–[85]. The Kruskal–Wallis test significance value p > 0.05 showed that limitations/emerging trends of mean scores are not significantly different [83], [86], [87]. The significant differences in mean scores of limitations and emerging trends were identified among the continents. Table VIII summarizes the tests and outcomes.
There was a significant difference in mean scores of responses across continents (Kruskal–Wallis ANOVA, $H = 12.546, df = 4, P < 0.014$) for the emerging trend that Green and Six Sigma are complementary to each other and where their integration would be beneficial. The mean values for North and South America and Europe are lower when compared with those for Africa and Asia. Green Six Sigma is a relatively new concept compared with Six Sigma [22]. In both Asia and Africa, the Green Six Sigma concept is gaining popularity, compared with other continents. Six Sigma experts perceived immense benefits to organizations when Green Six Sigma is applied to Africa and Asia compared with countries which have already established the Green initiatives.

The mean scores of emerging trend of integration of Six Sigma and Industry 4.0 were found to be significantly different across the continents (Kruskal–Wallis ANOVA, $H = 17.032, df = 4, P < 0.002$). The mean scores in Europe and North America are lower compared with other continents as Industry 4.0 is implemented in Europe and North America to a large extent compared with other continents. The mean scores of emerging trend of the integration of Six Sigma with Big Data (with the potential to provide superior results in many organizations in the future) are significantly different across the continents (Kruskal–Wallis ANOVA, $H = 10.637, df = 4, P < 0.031$). Six Sigma experts from Europe have lower mean values compared with other continents. The mean scores of emerging trend that Six Sigma is not suitable for public sector organizations are significantly different across the continents (Kruskal–Wallis ANOVA, $H = 20.1, df = 4, P < 0.000$). The Six Sigma experts from Africa have higher mean values compared with those from other continents. In Africa, public sector underperformance is due to various factors beyond the control of organization, such as political interference and terrorism [88], [89]. Therefore, in the African context, Six Sigma may not be effective in solving external problems as these may be beyond the control of the organization, leading to Six Sigma experts perceiving it to be less effective in the public sector. The limitation of the failure rate of Six Sigma initiatives, similar to other organizational change initiatives, is very high, but the mean scores are found to be significantly different across the continents (Kruskal–Wallis ANOVA, $H = 14.060, df = 4, P < 0.007$). The perspectives of organizational change in Asia is different compared with other continents due to its socio-cultural dynamics [90]. The successful implementation of Six Sigma requires a successful organizational change management program [91], which takes care of contextually relevant socio-cultural factors. In the Asian context, the nonhandling of these dynamics transmutes to a high failure rate, and, thus, the Six Sigma experts in Asia felt that the Six Sigma initiatives similar to other organizational change initiatives are very high.

### B. Limitations and Emerging Trends of Six Sigma Sector-Wise Analysis

The limitations and emerging trends are also analyzed on a sector-wise basis. The Six Sigma experts from manufacturing, service, and public sectors participated in this research.

| Limitations | Sum | Mean Scores |
|-------------|-----|-------------|
| Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly | 847 | 5.72 |
| Integration of Six Sigma with Big Data can bring superior results to many organizations in the future | 827 | 5.59 |
| Poor implementation of Six Sigma can have a negative impact on employee satisfaction. | 824 | 5.57 |
| Variance reduction should not be the only goal of Six Sigma implementation | 816 | 5.51 |
| Integration of Six Sigma and Industry 4.0 is not fully explored yet and it will be one of the next big emerging topics | 770 | 5.21 |

### Table IX

| Limitations | Sum | Mean Scores |
|-------------|-----|-------------|
| Integration of Six Sigma with Big Data can bring superior results to many organizations in the future | 801 | 5.8 |
| Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly | 781 | 5.66 |
| Variance reduction should not be the only goal of Six Sigma implementation | 777 | 5.63 |
| Poor implementation of Six Sigma can have a negative impact on employee satisfaction. | 753 | 5.46 |
| Green and Six Sigma are complementary to each other and their integration would be beneficial to many companies | 703 | 5.1 |

### Table X

| Limitations | Sum | Mean Scores |
|-------------|-----|-------------|
| Variance reduction should not be the only goal of Six Sigma implementation | 120 | 5.71 |
| Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly | 118 | 5.62 |
| Integration of Six Sigma with Big Data can bring superior results to many organizations in the future | 115 | 5.48 |
| Poor implementation of Six Sigma can have a negative impact on employee satisfaction. | 111 | 5.29 |
| Integration of Six Sigma and Industry 4.0 is not fully explored yet and it will be one of the next big emerging topics | 107 | 5.1 |

### Table XI

Table IX–XI depict the top five limitations of Six Sigma as perceived by the Six Sigma experts.

In the manufacturing sector, the emerging trends of Six Sigma in SMEs and microenterprises are very challenging but could be very rewarding if implementation was prioritized, resourced, and carefully managed. However, SME and microenterprises find it very challenging to implement Six Sigma. As SMEs are not aware of Six Sigma or its limitations, many do not have the resources to implement six sigma project [92]. Interestingly, Six Sigma can be deployed in both large corporations and small companies [36]. However, the use of Six Sigma in SMEs is not very common due to various misconceptions about the topic.
and a lack of understanding and awareness of the benefits of Six Sigma in the SME context [24]. Thus, there is a need for an implementation guideline for Six Sigma in SMEs for use in the manufacturing sector in order to mitigate challenges.

In a modern factory, machines are connected as a collaborative community requiring the utilization of advance-prediction tools, in order for Big Data to be systematically processed into information to explain uncertainties, and thereby make more “informed” decisions to create service innovations [93].

Therefore, the Six Sigma experts in the service sector perceived the top emerging trend to be the integration of Six Sigma with Big Data, which can bring superior results to many organizations in the future. The variability within the service sector is encountered in many components, interfaces, and entities interacting within its systems. Variability could be due to different usage situations and conditions, operator-introduced variations in operating the system, and customer-introduced variability in service operations [94]. The objective of public service is to serve people from different strata of the society and thus leading to different requirements needs. Consequently, variance reduction is not the only goal of Six Sigma implementation. An important subject that is worth investigating is the question whether there was any significant difference in mean scores of Six Sigma experts across the sectors studied. As the data were nonnormal, the Kruskal–Wallis test was conducted.

The mean scores of emerging trend of the integration of Six Sigma and Industry 4.0 are not fully explored yet, and the perception differed significantly across the sectors (Kruskal–Wallis ANOVA, $H = 10.241, df = 2, P < 0.006$) suggesting that it would be one of the next big emerging topics. The manufacturing sector mean score was higher, suggesting that the concerns among experts in the manufacturing sector include a need for an integration methodology to guide the manufacturing sector through the integration. As Industry 4.0 has first been applied in the manufacturing sector rather than the service sector, Six Sigma experts perceived its importance for manufacturing compared with services. The mean scores of limitation of nonstandardization of the training/education curriculum were perceived to be significantly different across the sectors (Kruskal–Wallis ANOVA, $H = 13.069, df = 2, P < 0.001$). The service sector mean values were higher than others suggesting that there is an urgent need to standardize Six Sigma curriculum for the use in the service sector. Six Sigma roll out in the service sector is a challenge [1], and, therefore, there is a need for the standardization of the curriculum in order for its effective implementation. The mean scores of limitation benefits accruing from Six Sigma implementation are minimal when compared with the effort invested was perceived differently across the sectors (Kruskal–Wallis ANOVA, $H = 13.069, df = 2, P < 0.001$). The public sector mean values were higher, given that Six Sigma is an emerging area in the public sector. Tangible benefits in the public sector could include a reduction in time, space, and cost, with improved quality and dependability impact and also efficiency and effectiveness. Intangible benefits in the public sector might include a better understanding of customers and cross-team synergies and a rise in employee motivation and morale. Six Sigma benefits in terms of tangible and intangible benefits in the public sector are often difficult to quantify. This could be due to the inherent nature of public service, as it is built on the fundamental principles such as democratic citizenship, community and civil society, and organizational humanism and discourse theory [95].

### C. Limitations/Emerging Trends of Six Sigma Belt-Wise Analysis

The limitations are also examined belt-wise. Tables XIII–XV depict the top five limitations as perceived by Master Black Belt, Black Belt, and Green Belt experts.

#### TABLE XII

| Sector-Wise | Manufacturing (N=140) | Services (N=138) | Public Sector (N=23) | Sum | Mean | Sig |
|-------------|-----------------------|-----------------|---------------------|-----|------|-----|
| Green and Six Sigma are not completely interrelated and their implementation would be beneficial to many companies | 796 | 5.32 | 703 | 5.10 | 104 | 4.25 | 0.751 |
| Integration of Six Sigma and Industry 4.0 is not fully explored yet and will be one of the next big emerging topics | 770 | 5.21 | 656 | 4.75 | 107 | 5.10 | 0.006 |
| Nonstandardization of Curriculum | 827 | 5.29 | 857 | 5.80 | 115 | 5.48 | 0.352 |
| Poor implementation of Six Sigma can have a negative impact on employee satisfaction | 599 | 5.26 | 627 | 4.95 | 88 | 5.23 | 0.005 |
| Six Sigma as a structured and disciplined approach to problem solving may affect the employee creativity and innovation | 824 | 5.27 | 753 | 5.45 | 111 | 5.22 | 0.471 |
| Six Sigma and Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly | 510 | 5.45 | 430 | 2.60 | 86 | 3.14 | 0.053 |

#### TABLE XIII

| Limitations                                                                 | Sum | Mean | Sig |
|-----------------------------------------------------------------------------|-----|------|-----|
| Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly | 847 | 5.72 | 781 | 6.06 | 118 | 5.82 | 0.488 |
| Six Sigma is not suitable for public service organizations                    | 913 | 5.37 | 554 | 3.05 | 83 | 3.25 | 0.352 |
| Six Sigma (Six Sigma in Lean and Six Sigma in Six Sigma if not implemented properly) | 751 | 5.27 | 679 | 4.95 | 102 | 4.65 | 0.562 |
| The benefits due to Six Sigma are not fully explored yet and will be one of the next big emerging topics | 351 | 5.27 | 375 | 2.72 | 67 | 3.19 | 0.012 |
| Nonstandardization of Curriculum                                            | 522 | 4.20 | 617 | 4.47 | 85 | 4.22 | 0.205 |
| The technical challenges of implementing Six Sigma on an organization are very high | 912 | 4.34 | 543 | 3.90 | 65 | 4.27 | 0.212 |
| Six Sigma and Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly | 610 | 4.32 | 540 | 3.91 | 81 | 3.90 | 0.513 |
| Variance reduction should not be the only goal of Six Sigma implementation  | 816 | 5.21 | 777 | 5.85 | 120 | 5.71 | 0.800 |

#### TABLE XV

| Top Five Limitations and Emerging Trends of Master Black Belt Experts |
|----------------------------------------------------------------------|
| Sum | Mean |
|-----|------|
| 756 | 5.85 |
The Master Black Belt standard provides technical leadership support for the Six Sigma program [96]. In a strategic and leadership sense, Master Black Belts have perceived that Six Sigma programs in SMEs and microenterprises are very challenging but also highlight that they could be very rewarding if implemented properly as the top limitation/emerging trends.

Black Belt status are technically oriented individuals held in high regard by their peers [96]. In this survey, they have identified the significance of Six Sigma alignment with Big Data. Therefore, they have perceived that the integration of Six Sigma with Big Data can generate superior results for many organizations in the future as the top limitation/emerging trends.

Green Belts are Six Sigma project leaders who are capable of forming and facilitating Six Sigma teams and managing Six Sigma projects from concept to completion [96]. Green Belt experts also identified Six Sigma integration with Big Data as an emerging trend, but they also perceived Six Sigma to have a negative impact on employees if it is not implemented properly. An important subject that is worth investigating is whether there was any significant difference in the perception of Six Sigma experts who are Master Black Belt, Black Belt, and Green Belt. Table XVI depicts the results of the belt-wise Kruskal–Wallis test and analysis.

The results suggest that six sigma as a structured and disciplined approach to problem solving that may stifle the employee creativity and innovation was perceived significantly different by Master Black Belts, Black Belts, and Green Belts (Kruskal–Wallis ANOVA, $H = 14.741$, $df = 2$, $P < 0.001$). The mean score of Green Belts was higher than Master Black Belt and Black Belt. The differences may be explained in terms of the ranking order of Belt experts as Green Belts usually assist Black Belts with their projects. In general, Black Belts guide Green Belts to define their project priorities [96]. Given the formalized relationship, Green Belts may have perceived that such a structured and disciplined approach stifles the employee creativity and innovation. The emerging trend of six sigma as not being suitable for public sector organizations was also perceived differently by different belt experts (Kruskal–Wallis ANOVA, $H = 19.803$, $df = 2$, $P < 0.000$). The Master Black Belts mean score was the lowest suggesting that those experts who are responsible for the strategic implementation of Six Sigma perceive that Six Sigma is suitable for public organizations. The limitation of Six Sigma is TQM on steroids and is perceived differently by Six Sigma experts (Kruskal-Wallis ANOVA, $H = 11.268$, $df = 2$, $P < 0.008$). The mean score of Green Belts was higher than those of Master Black Belts and Black Belts. As the Green Belt training is shorter (in terms of projects content and experience) in comparison with other belt training, it is likely that Green Belts may not appreciate the uniqueness of Six Sigma compared with TQM or other quality management programs. The distribution of technical limitations of Six Sigma (for example 1.5σ shift) that needs to be addressed to instill confidence in organizations to implement Six Sigma is perceived differently by the Six Sigma experts with different belt levels (Kruskal–Wallis ANOVA, $H = 13.397$, $df = 2$, $P < 0.003$). The 1.5σ shift was one of the most controversial topics among the Six Sigma experts [97]. The Master Black Belts and Black

### TABLE XIV

| Limitations                                                                 | Sum | Mean Scores |
|----------------------------------------------------------------------------|-----|-------------|
| Integration of Six Sigma with Big Data can bring superior results to many organizations in the future | 574 | 5.68        |
| Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly | 572 | 5.67        |
| Variance reduction should not be the only goal of Six Sigma implementation | 558 | 5.53        |
| Poor implementation of Six Sigma can have a negative impact on employee satisfaction | 549 | 5.44        |
| Green and Six Sigma are complimentary to each other and their integration would be beneficial to many companies | 527 | 5.21        |

### TABLE XV

| Limitations                                                                 | Sum | Mean Scores |
|----------------------------------------------------------------------------|-----|-------------|
| Integration of Six Sigma with Big Data can bring superior results to many organizations in the future | 319 | 5.6        |
| Poor implementation of Six Sigma can have a negative impact on employee satisfaction | 311 | 5.46        |
| Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises are very challenging but could be very rewarding if implemented properly | 307 | 5.39        |
| Variance reduction should not be the only goal of Six Sigma implementation | 301 | 5.28        |
| Six Sigma, if not implemented properly, may have a negative impact on customer satisfaction | 300 | 5.26        |

### TABLE XVI

| Belt-wise Kruskal–Wallis Test on Limitations and Emerging Trends of Six Sigma |
|---------------------------------|--------|--------|--------|--------|
| Limitations | Black Belt (N=121) | Green (N=75) | Master Black Belt (N=131) | Kruskal–Wallis test |
|-------------|-------------------|-------------|---------------------------|---------------------|
| Sum         | Mean              | Sum         | Mean                      | Sig                 |
| Green and Six Sigma are complimentary to each other and their integration would be beneficial to many companies | 572 | 5.67 | 571 | 4.27 | 6.14 | 0.68 | 4.99 | 0.479 |
| Integration of Six Sigma and Big Data is not fully aligned yet and will be one of the next big emerging topics | 558 | 5.53 | 5.04 | 4.73 | 5.05 | 0.64 | 4.93 | 0.535 |
| Poor implementation of Six Sigma can have a negative impact on employee satisfaction | 549 | 5.44 | 5.40 | 5.04 | 5.64 | 5.71 | 5.59 | 0.673 |
| Green and Six Sigma are complimentary to each other and their integration would be beneficial to many companies | 527 | 5.21 | 5.13 | 3.62 | 5.38 | 2.87 | 0.001 |
| Six Sigma is not suitable for public sector organizations | 372 | 5.67 | 5.03 | 5.26 | 5.76 | 5.85 | 0.099 |
| Six Sigma is not suitable for public sector organizations | 319 | 5.64 | 3.21 | 2.94 | 2.03 | 2.22 | 1.71 | 0.003 |
| Six Sigma in TQM on steroids | 391 | 5.09 | 3.80 | 4.21 | 4.31 | 5.32 | 0.003 |
| If implemented properly, may have a negative impact on customer satisfaction | 327 | 5.27 | 4.85 | 5.26 | 6.32 | 4.67 | 0.225 |
| The benefits due to Six Sigma implementation | 281 | 5.24 | 2.83 | 3.03 | 3.15 | 2.40 | 0.003 |
| The benefits due to Six Sigma implementation | 416 | 4.12 | 4.30 | 4.71 | 5.93 | 4.34 | 0.201 |
| Six Sigma is an organization in very high performance | 495 | 4.92 | 4.69 | 4.90 | 5.14 | 5.92 | 0.135 |
| The benefits due to Six Sigma implementation | 493 | 4.95 | 4.67 | 4.96 | 4.81 | 4.97 | 0.003 |
| Variance reduction should not be the only goal of Six Sigma implementation | 569 | 5.63 | 5.01 | 5.28 | 7.14 | 5.70 | 0.127 |

*Significant $p < 0.05$. 

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Belts mean scores were lower compared with Green Belts. This suggests that as the experts spend more time on theoretical and practical aspects of Six Sigma, they have more clarity regarding technical limitations. The limitations that benefits due to Six Sigma implementation for companies are minimal with respect to the efforts perceived differently by the Six Sigma experts with different belt levels (Kruskal-Wallis ANOVA, $H = 12.725$, $df = 2$, $P < 0.005$). The mean scores of Green Belts are higher compared with Master Black Belts and Black Belts suggesting that as one gains knowledge and experience in Six Sigma, the appreciation of Six Sigma benefits with respect to efforts improve.

### D. Limitations/Emerging Trends of Six Sigma Experience-Wise Analysis

This article conducted an analysis of Six Sigma experts’ perceptions based on their number of years’ experience. For the purpose of the analysis, the experience categories were classified as Six Sigma experts with less than five years of experience and those with more than five years of experience. The analysis was conducted on both categories. Tables XVII and XVIII summarize the top five limitations associated with expert’s experience in each category.

The experts with less than five years of experience were more concerned with emerging trends, such as Big Data, whereas experts with more than five years of experience suggest that the importance of Six Sigma in SMEs and microenterprises is very challenging but could be very rewarding if implemented properly.

An important matter, which is worth investigating, is whether there was any significant difference in the perception of Six Sigma experts who are more experienced on the Six Sigma limitations/emerging trends. Table XIX depicts the experience-wise analysis.

The technical limitations such as the 1.5 $\sigma$ shift, need to be addressed in order to instill confidence in organizations in their implementation of Six Sigma (Mann–Whitney U Test statistic $= 7478.0$, $P < 0.013$). As the mean score of more
experienced experts was lower, it suggests that as the experts gain more experience such technical limitations become more understood and less of an issue for the experts.

The limitation variance reduction should not be the only goal of six sigma implementation that is perceived differently by the experts (Mann–Whitney U Test statistic = 10 534.5, P < 0.03). The experienced experts (with more than five years of experience) mean scores were significantly higher than those with less than five years of experience suggesting variance reduction should not be the only goal in Six Sigma projects. Such an approach is very important in-service sectors, as variability is not always viewed as negative in the service sector.

V. CONCLUSION

The purpose of this article was to identify the limitations/emerging trends of Six Sigma from the viewpoint of Six Sigma experts from different continents, belt-wise, years of experience in Six Sigma, and in different sectors. Through an online survey, the Six Sigma experts identified the limitations/emerging trends of Six Sigma. The analysis focused on identifying the top five limitations/emerging trends from Six Sigma experts by continent, sector, Six Sigma belt, and experience of Six Sigma experts.

The integration of Six Sigma with Big Data was found to be the topmost emerging trend among Asian, South America, and Africa experts. Experts in Europe and North American in addition to experts from manufacturing sector agreed that Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises would be very challenging, however will be very rewarding if implemented properly. In service sector, the integration of Six Sigma with Big Data is the topmost emerging trend, and public sector experts felt variance reduction should not be the only goal of Six Sigma implementation.

The master black belts and experts with more than five years of experience perceived that Six Sigma in Small and Medium Sized Enterprises and Micro-enterprises is very challenging, but would be rewarding if implemented properly, whereas Black and Green Belts perceived Integration of Six Sigma with Big Data. However, Six Sigma expert with less than five years of experience felt integration of Six Sigma with Big Data.

The first limitation of this research was the representation of all continents. As the response rate from some continents was very low, the continent of Australia was not included in the study. The second limitation involved the use of a single-item scale for each limitation/emerging trend. The third limitation of the study considered the general limitation of survey design, where memory decay could influence the study. To mitigate this limitation, perceptual experts’ data from Six Sigma experts with Green, Black and Master Black belts was used.

This is the first global research to quantitatively analyze the limitations and emerging trends of Six Sigma from data obtained by Six Sigma experts. Future research should be directed on the emerging trends. The integration of Six Sigma and Industry 4.0 is not fully explored yet, and future research should investigate the development of an integration framework. The integration of Six Sigma with Big Data can provide superior results to many organizations, and future research should be directed to the development of new tools for Big Data analysis. In addition, the existing tools can be further modified to incorporate Big Data. Green Six Sigma research is in the preliminary stages, and therefore a well-established generic framework for its implementation is also needed. Six Sigma in public sector organizations is an underresearched subject, and future research study should be directed in different public services where Six Sigma can be implemented. Six Sigma in SMEs and microenterprises research should also be expanded for the purpose of developing an implementation framework, tools, curriculum development and trainings, etc.

A. Theoretical and Practical Implications

Six Sigma as a business strategy is used by many organizations for process improvement since nearly last four decades and is reported to have saved millions of dollars for various organizations despite of their nature—service, manufacturing, and public sector. Previous studies have also reported limitations of Six Sigma along with modern trends considering the changing face of modern organizations due to fourth industrial revolution. This article evaluates the limitations and emerging trends of Six Sigma from the perspectives of Six Sigma experts through a global survey and thus being the first study to evaluate the limitations and emerging trends globally. Understanding the major limitations/emerging trends/research gaps will create a foundation for both industrial experts and leading academic scholars for a greater understanding on the existing gaps so that further research can be executed to address them in the forthcoming years. Furthermore, it can form the basis upon which to discuss and develop combined academic and industry strategies to address and overcome these limitations. This article suggests that the importance of integration of Six Sigma with Big Data and Industry 4.0 has been a major emerging trend that researchers and practitioners must exploit. Researchers can use the results of this research to develop an implementation framework that integrates Big Data and Six Sigma and that will benefit the practitioners. Industry 4.0 further stresses the importance of vertical, horizontal, and end-to-end integration in a goal-directed manner to achieve business excellence. The authors believe that practitioners can use this research to integrate Six Sigma methodology with Big Data throughout the three phases of integration. This article also suggests the need for Six Sigma practitioners to customize the Six Sigma methodology further to implement the same in small, medium, and microenterprises as there is yet no practical and proven frameworks exist in authors’ opinion. Green Six Sigma is another aspect that senior managers should consider while applying the green principles and concepts in their organizations. Managers can further consider having tangible green objectives in terms of decreasing emissions, energy consumption, waste and environmental costs, at the same time increasing environmental revenues while designing Six Sigma process improvement strategies. Although this is not seen as a short-term strategy to be adopted for many organizations, the authors argue that the integration of Green with Six Sigma will be of great demand in the forthcoming years, especially when
the agenda for environmentally products become a priority for organizations.

ACKNOWLEDGEMENT

The authors would like to thank all the participants in the online survey for responding despite their busy schedule and the reviewers for constructive feedback, which have improved the quality of this article.

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