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Author(s)	Antony, Jiju; McDermott, Olivia; Sony, Michael
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Revisiting Ishikawa's Original Seven Basic Tools of Quality Control: A Global Study and Some New Insights

Jiju Antony, Olivia McDermott, and Michael Sony

***Abstract*—The purpose of this global study is to investigate the validity of Dr. Ishikawa's statement that "95% of problems in processes can be solved using the 7 Quality Control (QC) tools" in organizations. An online survey instrument was developed, disseminated, and responded to by a total of 456 senior quality professionals from five different continents. The main finding of this article suggests that less than 25% of participants perceived that the seven tools of QC can solve above 95% of quality problems while 40% of quality professionals stated that they had incorrectly applied the tools "right first time" during the problem solving. Pareto analysis was the most widely used tool across all sectors while the least used tools are scatter diagrams and stratification. The seven QC tools were widely utilized in production or manufacturing areas but least applied in IT and finance functions. The common benefits from the use of seven basic tools of QC in all sectors include: providing structure to the problem-solving efforts; aids problem solving and helps in problem definition, measurement, and analysis. This article presents a list of critical success factors (CSFs) required for the proper application of the seven QC tools including having management support and a commitment to tool usage as well as having a continuous improvement initiative to encourage tool usage. This article is the first global research focused on investigating Dr. Ishikawa's statement: "95% of problems in processes can be solved using the 7 QC tools." The findings further facilitate an important first step toward understanding the applicability, benefits, CSFs, and challenges to utilizing these tools in organizations across sectors and globally.**

***Index Terms*—Quality, quality control (QC), quality improvement, quality management, surveys, tools.**

I. Introduction

THE globalization currently affecting our societies has resulted in increased economic competition and a growing awareness of the value of quality management for success. Therefore, business enterprises have strengthened their efforts to achieve a high quality level, which has led to the recognition of quality as a key strategic factor in achieving business success [1]. Many authors writing on the subject of quality management have agreed that the use and selection of quality management tools and techniques are vital to support and develop the quality improvement process [2]. Tools and techniques are practical methods, skills, means, or mechanisms that can be applied to tasks. Among other things, they are used to facilitate positive change and improvements [3]. The development of quality management was influenced by several American and Japanese Quality "gurus," one of which was Dr. Kaoru Ishikawa. Ishikawa was known for his work on quality circles education and training in the use of continuous improvement. He put forward seven basic tools of quality control (QC), which he stated, were vital for problem solving, these include check sheets, histograms, Pareto analysis, cause and effect diagrams, control charts, scatter diagrams, and stratification [4], [5].

In his book "Introduction to Quality Control" Ishikawa [5] stated, "the tools, if used skilfully, will enable 95% of workplace problems to be solved and intermediate and advanced statistics are needed in about 5% of cases." However, Ishikawa was not very prescriptive outside of this statement and did not elaborate or explain where this figure came from or how it could be measured [5]. This article revisits the statement made by Ishikawa that 95% of problems can be solved using his seven QC tools. This statement has not been questioned or analyzed to date. It is very unclear whether his statement was solely referring to the usage of the tools in the manufacturing sector or across other sectors. It is also unclear whether individual tools are utilized more than others in the problem-solving process in comparison to other tools. The use, effectiveness, and application of the tools in other functions or departments outside of manufacturing and production areas is also unclear and is one of the main purposes of this article. In this article, the authors are carrying out a global research study specifically with the purpose to establish how widespread the use of the seven QC tools is and where the tools are utilized and in what functions. The authors are keen to explore the usage of the tools across different contents and countries.

The authors were keen to explore following research questions.

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Jiju Antony is with the Industrial and Systems Engineering, Khalifa University, Abu Dhabi 127788, UAE (e-mail: jiju346@googlemail.com).

Olivia McDermott is with the College of Science and Engineering, National University of Ireland Galway, Galway H91 TK33, Ireland (e-mail: olivia.mcdermott@nuigalway.ie).

Michael Sony is with the Department of Mechanical & Marine Engineering, Namibia University of Science and Technology, Windhoek 13388, Namibia (e-mail: emailofsony@gmail.com).

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1) *Does Ishikawa's statement that the seven QC tools can solve 95% of problems have validity in modern organizations?*
2) *How frequently are the seven QC tools applied in organizations and in what functions are they deployed?*
3) *What are the CSFs benefits and challenges to applying the seven QC tools?*
4) *How often is the incorrect or "wrong" QC tool utilized in problem-solving situations?*

These four research questions aforementioned form the foundation and purpose of this research, and Ishikawa has never answered these questions in his writings. This article as part of a global study will demonstrate that outside of both the manufacturing sector and the production or manufacturing departments or functions that the usage of seven QC tools is not as prevalent in other functions and sectors. This study challenges the statement by Ishikawa that the tools are basic and easily understood and applied by all levels of employees in an organization once training is given [4], [6]. The research also analyzes the level of application and frequency of usage of the seven QC tools; some of which are used rarely while others are used frequently.

The rest of this article is organized as follows. Section II presents a review of the literature. Section III illustrates the research methodology adopted for the study. Section IV presents the key findings of the global study. Section V discusses the findings and implications. Finally, Section VI concludes this article.

II. Literature Review

An important principle of quality management as advocated by the quality gurus, such as Deming, Juran, and Feigenbaum, is that everyone should be involved in the quality management process and in continuous improvement initiatives [7]–[9]. The seven traditional tools of QC or the basic seven tools of QC, developed by Dr. Kaoru Ishikawa, are a set of graphical techniques identified as being very useful in problem solving issues related to quality improvement projects [10].

Problem solving is the process of working through the details of a problem by applying appropriate technology, tools, and decision-making techniques to identify a root cause and to implement a solution. Root cause analysis (RCA) is a step-by-step process of observing, investigating, analyzing, and determining the source of a problem to prevent a recurrence of the same problem [11]. These problem-solving tools are considered "basic" because individuals with little or no training in statistics can use them to perform RCA and solve many quality-related and process-related problems in organizations [12].

Quality tools are primarily used to understand analyze and improve processes [4]. A single tool may be described as a device that has a clear role. It is often narrow in focus and is usually used on its own, whereas a "technique" tends to be a more comprehensively integrated approach to problem solving that might rely on a number of supporting tools. An example of this is statistical process control (SPC), where the production of a control chart is an essential application of charting skills. When viewed simplistically, techniques are a collection of tools and both develop a mindset for continuous improvement in an organization [3].

Dr. Ishikawa believed that superior quality is readily accepted anywhere in the world; that companywide QC should embrace the doctrine that human nature is fundamentally good; and that QC begins and ends with education [13]. Dr. Ishikawa also believed in the use of simple tools, teamwork, education, and training to solve problems and removing obstacles to quality and continuous improvement [14]. There is no shortage of the literature that describes the application of the basic seven QC tools and other techniques in various depths. Many of the quality gurus have written about quality management tools and their use including Dr. Juran and Dr. Ishikawa as well as other authors [2], [3], [15]–[17].

Much has been written on the benefits of the seven basic QC tools for as a reliable strategy to achieve sustainable business improvements [11], [18]–[20]. The tools are invaluable for highlighting complex data in a simple visual manner, evaluating areas that cause the most problems; enabling prioritization of problem areas, showing relationships between variables; establishing root cause, showing the distribution of data [12], [20]–[24]. The main aim of utilizing quality tools are to improve the communication between all levels of employees of an organization and find problems and the root causes of these problems [12], [25], [26]. The basic seven tools of quality can be applied to many processes including public, educational, financial, and service sectors and not just manufacturing, and are an integral part of a Six Sigma problem-solving methodology [27], [28].

The advantage of problem-solving tools are that they allow processes to be monitored and evaluated; everyone to become involved in the improvement process; people to solve their own problems; a mindset of continuous improvement to be developed; a transfer of experience from quality-improvement activities to everyday business operations and a reinforcement of teamwork through problem solving [3].

Ishikawa stated in his "Introduction to Quality Control" referring to the seven tools that "the tools, if used skillfully, will enable 95% of workplace problems to be solved and intermediate and advanced statistical tools are needed for about 5% of cases" [6]. Ishikawa referred to the seven basic tools as "introductory" aimed at all employees from management to ordinary workers. He also stated that "Intermediate" methods aimed at general engineers and workplace supervisors should be taught in addition to the introductory methods for example: distribution of statistics, sampling estimation correlation, and regression analysis and that "advanced" level methods be taught to specialist quality engineers in addition to the introductory and intermediate methods, e.g., design of experiments (DOE), time-series analysis, advanced reliability techniques, etc. [4].

He restated in his "What is Quality Control?" book in 1995 that "95% of problems in processes can be accomplished by the use of the 7 QC tools" and that only in very complex situations should advance tools and techniques and computers be a requirement. Ishikawa did not expand or explain this statement in any great detail. He also stated that for most problems; it was found when utilizing the Pareto principle that there were two or three assignable causes, so eliminating these will halve the number of defectives, e.g., raise the yield from 60% to 80% or 90% to 95%; so, thus, 95% of problem can be solved utilizing the seven QC tools [20]. Ishikawa did not elaborate on the use of the tools in other industries or as highlighted by He *et al.* [29] on the fact that the tools are not very capable of dealing with attribute data as six of the tools are focused on numerical or continuous data. Indeed, some critics of the seven old tools have stated that the "old" tools are retrospective and only look at existing problems. The "old" tools are too dependent on data collection and analysis, and not qualitative enough to be focused on wider company problems and strategic management planning [30], [31].

Some authors have selected particular tools as tools which to utilize in problem-solving efforts—the amount and quality of usage of these tools can vary totally [18]. Ishikawa, however, was specific in comparison to other authors that just seven tools could solve 95% of problems while some authors have referenced the use of one tool as a prerequisite to the use of another tool [20].

Quality tools and techniques usage can be limited due to lack of training and awareness regarding the benefits in the use and application of them [32]. According to Bamford and Greatbanks [27], very few examples have been found where even the basic seven quality management tools have all been fully exploited. Some authors have described the tools as too simplistic in some cases and not appropriate [33]. The typical difficulties according to McQuater *et al.* [3] with the use and application of tools and techniques are poor training and support; no opportunity to apply the tools; incorrect use of tools and techniques; resistance to the use of tools and techniques; lack of management support, and not sharing and communication of the benefits achieved.

The importance of soundly based, well taught out training in applying tools and techniques is important and introducing in relation to a defined need were better understood and utilized than those that were applied company-wide and without a specific use in mind at the time of the training [2]. The challenges in applying the quality management tools and techniques in other functions of an organization outside of manufacturing relate mainly to the focus on improvement projects and the resources available to facilitate the introduction and use [2], [17].

There are several factors involved in achieving the successful use and application of quality management tools as part of a process of continuous improvement. User friendliness and usefulness are the important factors in selecting quality tools as well as necessity and the organizational factors including top management support, teamwork, and technical capability [34], [35]. Time involved to train on use of the tools and ignoring data signals, picking, and choosing tools, which may not be appropriate, and lack of employee involvement and follow up on corrective actions can all contribute to failure in utilizing the tools [2], [17]. According to Dr. Ishikawa, TQC involves everyone in an organization to produce the right product that meets expectations including top management, every function within the company, and all employees [17]. Empowering personnel to aid successful quality improvement process and make decisions about their own work and environment can encourage people to use tools and techniques [3], [36].

In order to ensure problem-solving tools are used efficiently and effectively, several critical success factors (CSFs) are required. These CSFs include full management support and commitment; effective, timely, and planned training; a genuine need to use the tool or technique; defined aims and objective for use; a co-operative environment and backup and support from improvement facilitators [37], [38].

Understanding the goal of utilizing a certain type of tool or technique, its prerequisites, benefits, and obstacles to implementation and use of tools are vital to success as is having enough resources to utilize the tools [18], [39]. Scheuermann *et al.* [40] and Ahmed and Hassan [28] have demonstrated that some QC tools are preferred and applied over others, and some preferred because of a preference for qualitative over quantitative tools or vice versa. Even when these tools are utilized, a piecemeal approach to implementation often results in suboptimal performance or, indeed, a complete failure. The popularity of a tool can also affect tool selection and usage [35]. Yet, the application of such tools is one of the least problematic aspects of any quality improvement initiative, and arguably provides the most direct and immediate improvement to a process [41].

There are many benefits to problem solving and its positive effects on quality costs discussed in the literature [42], [43]. While examples in the literature of the effects of utilizing the incorrect QC tool in problem solving are sparse—many authors refer to applying the tools and utilizing specific tools in specific situations and organizations and the importance of doing so [3]. Problem solving can be complex and utilization of the incorrect QC tool can lead to delays and not solving the problem under study fully [41], [44]. Problem solving and its complexities means that the utilization of the incorrect problem-solving tool can lead to the wrong root cause and potentially an incorrect corrective action(s) and having to restart the RCA all over again [5]. This might result in hefty costs to many organizations and employee morale will be an issue in many cases.

A single tool/technique may not be a solution to all issues while a combination of tools can be used to demonstrate relationships [2], [41]. The use of the "right" tool is a common theme in studies about the use and application of QC tool(s) [27], [39]. Ensuring the user utilized and identified the correct and appropriate tool at the right stage of the problem-solving process is very important to the result [45]. Lack of understanding of the tools and when, where and how to apply them is the root cause of the failure to implement quality tools [32].

Many authors have referred to the fact that it is remarkable that many of these simple, yet powerful tools are not fully integrated within the day-to-day process improvement aspects of business and industry [27]. There can be many difficulties with using QC tools including not knowing what quality tools to use; utilizing the incorrect tool and not knowing when to use a quality tool [45]. Many difficulties in the implementation and usage of quality tools can be the lack of time to utilize tools, difficulties with understanding how to use the tools and associated terminology, the terminology in tool usage, reticence to provide resources to utilize the tools and lack of flexibility in how tools are applied [2], [30]. It can be difficult to measure the costs of utilizing the incorrect QC tool, but time delays, resource wasting, and costs of poor-quality product continuing to the customers and the resulting increased customer dissatisfaction [42]. Also, as six of the basic tools of QC are used for analyzing numerical data, some critics have stated that they are not very capable of dealing with nonnumerical data so this could lead to the wrong tool being utilized [29].

Authors further consider that solving quality problems is not only a matter of usage of seven quality tools. Furthermore, it is very difficult to contend that Dr. Ishikawa in his original work documented the existence of cornerstone causes, especially when he designed these tools such as the Ishikawa diagram in the 1960s [46]. In a modern-day organization, there are corner stone causes such as "the design of an organizational structure," "inefficient leadership," "failures in the flow of information," or "the lack of pride in doing the work." Such corner stone causes warrants an analysis much more than a simple analysis with these seven QC tools [46]. Thus, solving modern problems warrants understanding of elements such as organizational learning, industrial psychology, design thinking, Kaizen, and even organizational architecture can be used as support coupled with these seven QC tools [46], [47]. Therefore, to solve modern day problems, there is a need for more complex methodologies such as Toyota Kata [48], [49] or Improvement Kata [50] to be used in conjunction with the seven quality tools. However, the use of seven quality tools remains the foundation tools, which an organization should utilize in their modern workplace.

III. Research Methodology

The authors used an online survey because it enables faster data collection and enables the obtaining of a large amount in a short period of time. Online surveys are cheap and easy to use, and enable the questionnaires to be sent to the respondents in a standardized manner [51], [52]. The survey instrument designed for this article was divided into two sections. The first section was devoted to collecting details about the participants and about the organizations in which they work. The second section was devoted to collect information about different aspects of the use of seven QC s tools. Before the start of second section, the authors asked a check question, "*Have you been trained on the seven tools of quality? (If NOT, please do not continue!)*". This was done to glean information about the seven QC tools from respondents who have knowledge of them. The authors have utilized a purposive sampling strategy to minimize the chance for selection error and to ensure inclusion of experienced and knowledgeable respondents for the study including quality directors, quality managers, quality engineers, quality supervisors, and other quality-related personnel [53]. As this was a global study in order to maximize the responses we used a modified Dillman approach [54]. In order to maximize response rate, we have utilized multiple strategies [55]. Most of the quality professionals have a LinkedIn account, as it is one of most widely used social-networking platform among professionals [56]. We created a public post outlining the detailed objective of the study. The quality professionals were contacted and details about the study was given to them. The respondents who agreed to the study were sent the questionnaire through multiple online delivery channels (e-mail, WhatsApp, or LinkedIn personal messaging system). The questionnaire was designed so that the professionals can complete it in shortest possible time [57]. This is because quality professionals are busy and an unnecessary long questionnaire would discourage them from completing [58], [59]. Check boxes were used wherever possible so that the professionals can complete the questionnaire with minimum effort [51]. Besides, the questionnaires were designed based on sound theoretical review. The questions and their sources are depicted in Table I.

During piloting, the time taken to complete the questionnaire was also noted and it was found to be 12 min $\pm$ 4 min. The revised questionnaire was sent to 2000 quality professionals (Director of Quality, Operational Excellence Professional, Quality Engineer, Quality Supervisor, Senior Quality Manager, etc.) in all five continents. The study used stratified sampling using continentwise as, the intention was to study seven quality tools usage in all continents. As the respondents in the study were quality professionals, the questionnaire was designed in English. In addition, care was taken such that question was designed in simple, clear language that could be understood by anyone with basic English knowledge. The contact information of these quality professionals was obtained from LinkedIn and each of the respondents was contacted through e-mail. A similar methodology was used by the authors in previous studies [57], [66]. To ensure the quality of the responses, following three criteria were used to select the respondents.

1) The respondents should be working as a quality professional in an organization.
2) They should be working in roles such as Director of Quality, Operational Excellence Professional, Quality Engineer, Quality Supervisor, Senior Quality Manager or in similar roles.
3) They should be working in manufacturing, service, or public-sector organizations.

This article was carried out for a period of 36 weeks. A total of 456 responses were received with a response rate of 22.8%. Easterby-Smith *et al.* [67] argue that a 20% survey response rate is widely considered to be sufficient. The job profiles of the respondents by continent are given in Table II.

The online questionnaire was sent out to all the participants on the same day. A time trend extrapolation method was used to test for the nonresponse bias [68]. In addition to account for social desirability bias, personal identifying details such as name, family name, national identification number, etc., were not asked in the study. In this test, we compared early and late respondents in each continent. The early respondents were those who responded within the first four weeks and late respondents were those in last four weeks [57]. Chi-square analysis was carried on the demographic variables and found to be not significant ($p > 0.05$). Furthermore, the questionnaire was designed using peer-reviewed articles. In order to reduce socially desirable responding, we have offered the participants anonymity and their names were not sought [69], [70]. The data were analyzed primarily by using percentages and frequency counts. In addition, chi-square tests would be used for testing the

TABLE I
SURVEY QUESTIONS

Sr No	Key research Questions	Sources	Description for construction of Questionnaire
	What % of people in your organization have been trained on the 7 tools of quality? What percentage of quality problems in your current business can be tackled using the 7 tools of quality promoted by Dr Ishikawa? What are the most used tools among the seven basic tools? What are the least commonly used tools?	[6], [8], [13], [16], [18][60][22]	Understanding existing state of training, use of tools to solve quality problems, and frequency of 7 quality tool usage
2	Do you apply these tools in other functions such as Marketing, Sales, R&D, Product Development, Production, Admin, HR, Admin, Supply Chain and Logistics, Customer care, IT and Finance?	[4], [13], [24], [60]–[63]	Frequency of tool usage of 7 quality tools in various functional departments of organization
3	What are the fundamental benefits of these seven tools? in your experience? What are the rudimentary challenges in the use of these basic tools in organisations in your experience? What are the success factors in the implementation and usage of the seven basic tools in organisations? How often have you utilised the "wrong" or "incorrect" QC tool in a problem-solving situation?	[6], [13], [23], [24], [60], [63]–[65]	Understanding the benefits, challenges, success factors and incorrect application of tool usage in organizations

TABLE II
JOB PROFILES OF THE RESPONDENTS BY CONTINENT

	Female	Male	Grand Total
Africa	12	34	46
Operational Excellence	2	2	4
Quality Director	1	2	3
Quality Engineer	7	16	23
Quality Manager	1	9	10
Quality Supervisor	1	5	6
Asia	8	32	40
Quality Consultant	1	1	2
Quality Director	3	8	11
Quality Engineer		8	8
Quality Manager	1	13	14
Quality Supervisor	3	2	5
Europe	70	158	228
Operational Excellence	12	42	54
Quality Consultant	2	8	10
Quality Director	6	25	31
Quality Engineer	19	24	43
Quality Manager	26	49	75
Quality Supervisor	5	10	15
North America	16	29	45
Operational Excellence	6	9	15
Quality Consultant		1	1
Quality Director	2	4	6
Quality Engineer	4	10	14
Quality Manager	3	4	7
Quality Supervisor	1	1	2
South America	28	69	97
Operational Excellence	11	24	35
Quality Consultant	1	4	5
Quality Director	1	2	3
Quality Engineer	8	18	26
Quality Manager	3	3	6
Quality Supervisor	4	18	22
Grand Total	134	322	456

relationships between categorical variables [57]. Furthermore, Fisher's exact test of independence has been used to check whether the proportions of one variable are different depending on the value of the other variable. Although we have a large sample size, it is small for the clusters or groups such as continent comparisons; therefore, we used Fishers exact test as it is recommended for small sample size [71].

IV. KEY FINDINGS

The study asked the respondents whether they were trained on the seven tools of quality. The cross-continent results are depicted in Fig. 1.

South America had the highest percentage of quality professionals not trained in the seven QC tools at 20% untrained (19/97) while Europe had 15.7% of quality professionals untrained (31/197). The analysis was also carried out sectorwise and is depicted in Fig. 2.

In the manufacturing sector, around 12% quality professionals are not trained, whereas in public and service organizations combined around 14% (21 /155) are not trained in seven QC tools. Fig. 3 demonstrates the percentage of quality problems in organizations currently that can be tackled using the seven basic tools of QC promoted by Dr. Ishikawa.

The authors' findings from the study suggest that around 22.6% (90/397) of respondents are in favor of Dr. Ishikawa's statement [4], [6]. The cross-continent analysis depicts 2% (1/41) in Africa, 23% (9/38) in Asia, 26% (53/197) in Europe, 23% (10/43) in North America, and 21% (17/78) in South America are in favor of Dr. Ishikawa. A chi-square test performed between the categories of the various continents and the percentage of quality problems that can be tackled using the seven basic tools of quality suggests that there was no significant association (p-value $= 0.128$). A chi-square test of independence showed that there was no significant association between experience of quality professionals and percentage of quality problems that can be tackled using the seven basic tools

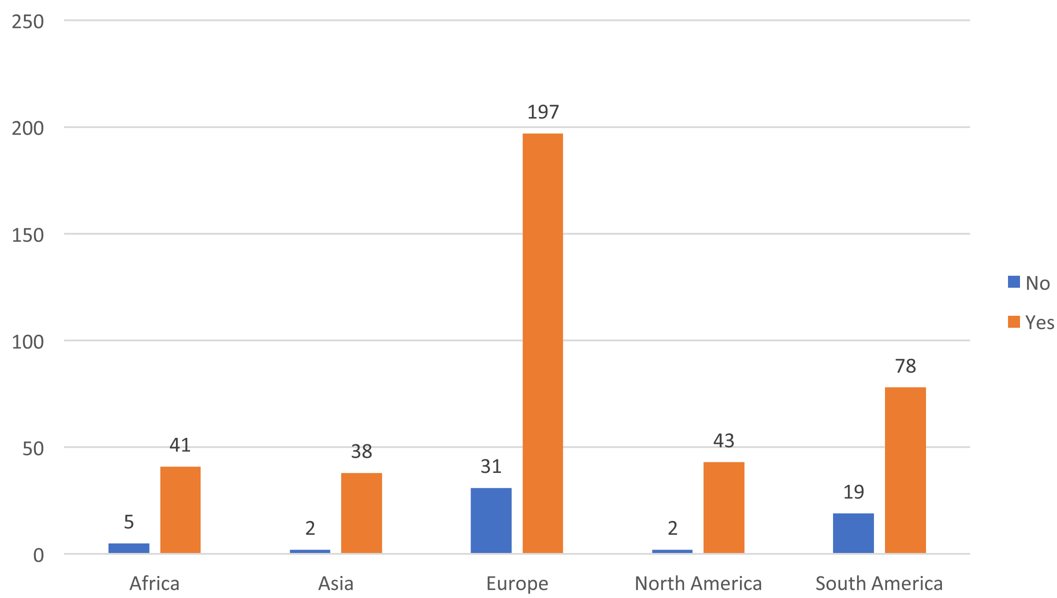

Fig. 1. Cross continent analysis of training in the seven tools of QC.

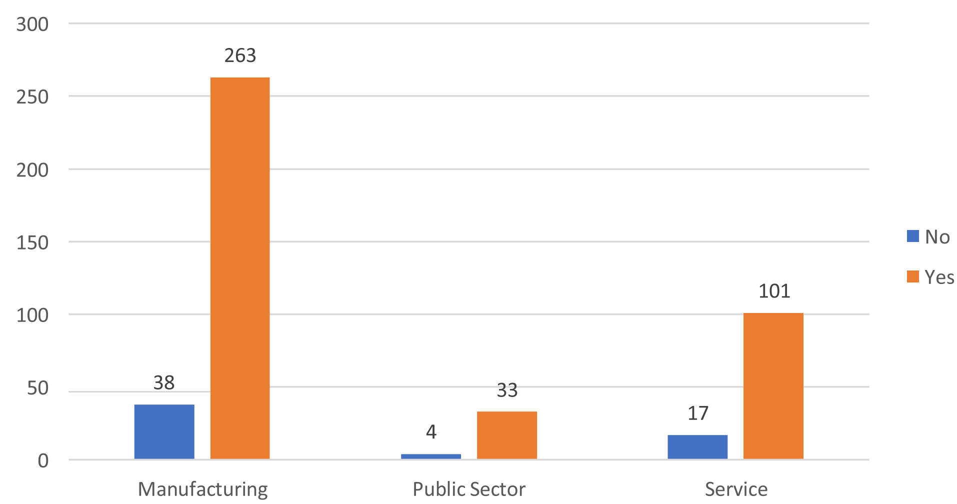

Fig. 2. Sectorwise analysis training in the seven tools of QC.

of quality (p-value = 0.344). A chi- square test of independence showed that there was significant association between sector type and percentage of quality problems that can be tackled using the seven basic tools of quality (p- value = 0.00108). This implies that a higher proportion of respondents in manufacturing sector view that Ishikawa's statement is not valid today than in the service sector. The chi-square table and data are elucidated in Appendix A.

The respondents were also asked about the usage of each QC tool across different functions within their organizations. There can be an operational difference in different functions and how they see quality. Their perspective can be biased based on how "close" they are to the final customer. In a sales function while the customer is first and foremost looked after in terms of delivering their requirements to increase revenue, sales personnel often work on commission. Thus, they may not be as focused on quality improvement and problem solving but they are revenue focused and will offer discounts and incentives when issues occur. Finance is focused on cost savings and perhaps do not see problem solving as top of their agenda as HR are focused on recruiting, performance planning, etc. In service organizations that are much more transactional and closer to their customers, quality can be deemed even more important. However, having time and resources for problem solving can be difficult as demand and operational tasks can be dynamic and unpredictable.

In all continents, it was found that the highest usage of seven QC tools is in the production function as compared to any other business functions included in the analysis such as sales, finance, marketing, IT, and HR (Table III).

Moreover, the findings also suggest that the seven quality tools are least used in IT and finance functions across all the

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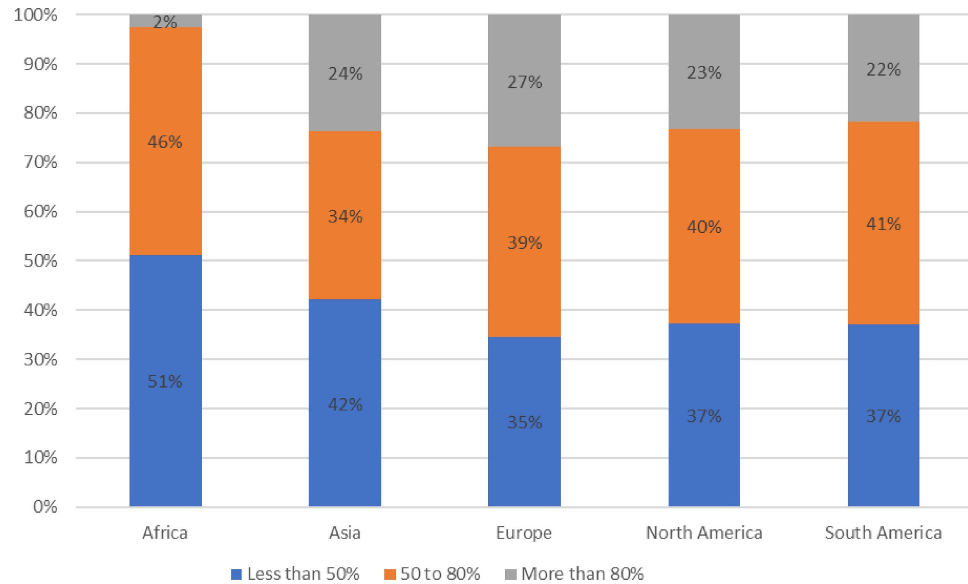

Fig. 3. Percentage of quality problems that can be tackled using the seven basic tools of QC by continent.

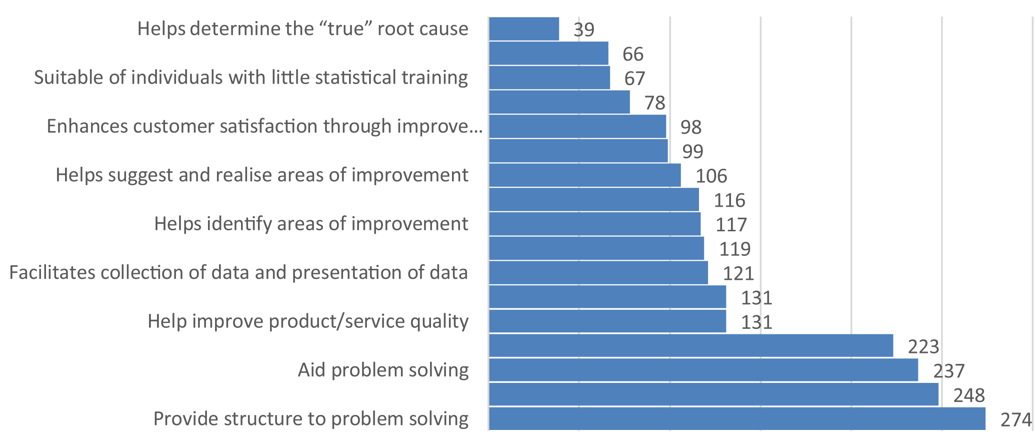

Fig. 4. Top benefits of utilizing the seven QC basic tools by frequency.

continents. Further analysis of data has also shown that the Pareto analysis has been used widely used in problem-solving scenarios across all five continents, whereas stratification and scatter diagrams were rarely used by the professionals. The authors observed that stratification was least used by quality professionals in Africa and used more often by professionals in South America. Table IV provides a sectorwise comparison of the usage of tools across different sectors, manufacturing, service, and public service sectors. For all sectors, the seven basic tools of QC were predominantly used in the production function. It was also realized that the most commonly used tool in production are control charts and the least commonly used tool was stratification. Another finding in the context of the manufacturing sector was that application of QC tools was least executed in the IT function. In the context of the service sector, the seven tools of QC were predominantly used in the production of services. It was also observed that control charts were the most commonly used tool, followed by cause-and-effect analysis in the service sector. Moreover, the application of QC tools was least deployed in the finance function, followed by HR and IT functions. In the context of public sector, the application of seven tools of QC was least executed in the development of new processes.

Fig. 4 presents the benefits of using the basic tools of QC according to participants of the global survey by frequency. The top five benefits across five continents are explicated in Tables V and VI presents the top benefits across sectors. The top five benefits of the use of seven QC tools derived from the whole set of data from the survey are: provide a structure to problem solving; help with problem definition, measurement, and analysis; aid problem solving; assists in continuous improvement projects, and help improve product/service quality. Moreover, the tools were not observed to be helpful in problem-solving exercises in the context of South America. The authors also found that the top four benefits across the three clusters of sectors (manufacturing, service, and public sector) were identical.

TABLE III
PROPORTION OF TOOL USAGE ACROSS DIFFERENT FUNCTIONS OF THE ORGANIZATION BY CONTINENT

		Sales	**Production**	**Supply Chain & Logistic**	**Customer Care**	**Finance**	**NPI&NPD (Product Development**	**Admin**	**IT**	**Marketing**	**HR**	**R&D**
Europe												
	Check Sheet	5%	28%	10%	8%	5%	14%	6%	4%	4%	4%	12%
	Scatter Diagram	6%	20%	8%	6%	6%	21%	2%	3%	6%	1%	21%
	Histogram	9%	19%	9%	7%	7%	12%	5%	4%	7%	6%	15%
	Pareto Analysis	10%	20%	9%	9%	7%	11%	4%	5%	8%	4%	13%
	Cause Effect Diagram	6%	22%	8%	10%	5%	14%	5%	5%	5%	3%	17%
	Stratification	11%	20%	8%	9%	7%	12%	2%	6%	8%	2%	15%
	Control Charts	6%	29%	9%	9%	6%	11%	3%	5%	6%	12%	4%
Asia												
	Check Sheet	11%	17%	9%	7%	3%	11%	11%	4%	6%	13%	8%
	Scatter Diagram	11%	20%	11%	4%	7%	11%	4%	4%	11%	6%	11%
	Histogram	13%	11%	8%	9%	6%	7%	8%	7%	13%	8%	10%
	Pareto Analysis	10%	14%	7%	9%	5%	11%	7%	6%	12%	7%	12%
	Cause Effect Diagram	8%	16%	7%	6%	7%	12%	11%	7%	8%	8%	10%
	Stratification	11%	18%	9%	7%	7%	7%	7%	4%	16%	3%	11%
	Control Charts	6%	23%	6%	10%	6%	13%	7%	6%	7%	14%	2%
North America												
	Check Sheet	6%	20%	13%	6%	3%	11%	15%	6%	8%	7%	5%
	Scatter Diagram	8%	21%	10%	8%	5%	8%	10%	8%	10%	5%	7%
	Histogram	6%	18%	14%	8%	7%	7%	14%	5%	9%	8%	4%
	Pareto Analysis	6%	20%	13%	7%	4%	9%	15%	5%	8%	7%	6%
	Cause Effect Diagram	5%	21%	12%	7%	4%	5%	16%	6%	7%	9%	8%
	Stratification	15%	9%	12%	9%	6%	6%	12%	6%	12%	4%	9%
	Control Charts	7%	22%	13%	6%	4%	7%	14%	6%	6%	7%	8%

The top five benefits in Table V were similar in terms of ranking across continents. Interestingly, the benefit of the tools for reducing the cost of quality and helping visibility of performance were not listed in the top five benefits across the four continents.

Table VI demonstrates major agreement between the public, service, and manufacturing sectors in terms of the benefits of the tools. Interestingly the public and service sector did not rate the benefits of the tool for helping improving product and service quality as highlighted as the manufacturing sector did.

TABLE III
CONTINUED

Africa												
	Check Sheet	10%	18%	8%	11%	5%	6%	8%	5%	12%	11%	6%
		Sales	**Production**	**Supply Chain & Logistic**	**Customer Care**	**Finance**	**NPI&NPD (Product Development**	**Admin**	**IT**	**Marketing**	**HR**	**R&D**
	Scatter Diagram	13%	28%	1%	12%	7%	7%	5%	3%	8%	7%	9%
	Histogram	10%	21%	8%	10%	3%	7%	8%	4%	12%	11%	6%
	Pareto Analysis	11%	30%	4%	11%	2%	8%	9%	2%	16%	4%	3%
	Cause Effect Diagram	8%	39%	5%	9%	3%	8%	3%	3%	9%	4%	9%
	Stratification	11%	21%	5%	11%	0%	5%	16%	0%	11%	4%	16%
	Control Charts	10%	40%	9%	10%	0%	5%	3%	7%	4%	5%	7%
South America												
	Check Sheet	9%	30%	12%	8%	3%	9%	8%	4%	5%	5%	7%
	Scatter Diagram	10%	28%	8%	7%	4%	9%	8%	5%	11%	2%	8%
	Histogram	12%	27%	10%	8%	5%	9%	7%	4%	8%	3%	7%
	Pareto Analysis	12%	23%	10%	8%	6%	7%	7%	6%	8%	6%	7%
	Cause Effect Diagram	9%	30%	9%	8%	4%	8%	8%	4%	6%	5%	9%
	Stratification	13%	24%	7%	10%	7%	10%	6%	5%	6%	7%	5%
	Control Charts	8%	35%	9%	6%	2%	11%	9%	4%	5%	7%	4%
Total Proportions		9%	23%	9%	8%	5%	9%	8%	5%	8%	7%	9%

However, both the service sector and public sector felt visibility of performance was a major benefit of the use of the seven QC tools while the manufacturing sector did not list this benefit in its top five.

Table VII reports the fundamental challenges in the use of seven basic QC tools across the participating organizations. The top five challenges according to our study are as follows:

1) lack of awareness and knowledge about the tools;
2) poor data collection methods;
3) lack of training;
4) lack of management support;
5) not using the right tools at the right time.

Some of the least reported challenges are poor communication, lack of teamwork, no need for the use of tools as we are different, and finally, the view that the basic tools of QC are meant for production function and are not applicable to other business functions in an organization. Table VIII shows the most important CSFs for the successful implementation of the basic tools of QC. These include the following:

1) management support and commitment;
2) integrating the tools within the existing CI initiative;
3) systematic and disciplined approach to solving problems;
4) participation of employees in a problem-solving context;
5) communication of the benefits at all levels across the organization.

Incorrect application of seven quality tools will not result in the desired outcomes. To capture the respondent's perception of incorrect tool usage, the respondents were asked "How often have you utilised the "wrong" or "incorrect" QC tool in a problem-solving situation." The question was personalized by adding you, and hence, there is a tendency for socially desirable responding [70]. In this research, personal identification details were never asked; however, this question was not made a compulsory question so that respondents do not feel threatened

TABLE IV
PROPORTION OF TOOLS USAGE ACROSS DIFFERENT FUNCTIONS SECTORWISE

	Sales	Production	Supply Chain & Logistic	Customer Care	Finance	NPI&NPD (Product Development)	Admin	IT	Marketing	HR	R&D
Manufacturing											
Check Sheet	6%	30%	11%	8%	3%	13%	5%	3%	5%	6%	10%
Scatter Diagram	7%	27%	7%	6%	5%	17%	2%	2%	7%	2%	18%
Histogram	9%	24%	9%	8%	5%	11%	4%	3%	8%	6%	13%
Pareto Analysis	10%	24%	9%	9%	5%	11%	4%	4%	8%	4%	12%
Cause Effect Diagram	7%	27%	9%	8%	4%	12%	5%	4%	4%	4%	16%
Stratification	10%	22%	7%	11%	5%	11%	5%	5%	8%	6%	10%
Control Charts	6%	35%	8%	8%	3%	12%	4%	4%	5%	3%	12%
Service											
Check Sheet	12%	15%	8%	8%	7%	8%	11%	6%	9%	10%	6%
Scatter Diagram	12%	16%	8%	9%	7%	9%	9%	7%	10%	6%	7%
Histogram	12%	13%	9%	8%	6%	8%	10%	6%	11%	9%	8%
Pareto Analysis	12%	15%	8%	8%	7%	8%	11%	8%	10%	7%	6%
Cause Effect Diagram	8%	19%	8%	9%	5%	9%	11%	7%	9%	7%	8%
Stratification	17%	16%	10%	7%	7%	8%	7%	4%	11%	3%	10%
Control Charts	9%	20%	11%	8%	6%	8%	9%	9%	8%	6%	8%
Public Sector											
Check Sheet	5%	15%	10%	12%	7%	5%	20%	7%	5%	12%	2%
Scatter Diagram	8%	17%	8%	13%	8%	4%	13%	13%	13%	3%	0%
Histogram	5%	10%	10%	10%	10%	4%	16%	9%	10%	10%	6%
Pareto Analysis	5%	12%	11%	11%	6%	3%	17%	9%	11%	11%	4%
Cause Effect Diagram	3%	15%	9%	9%	11%	3%	21%	8%	3%	14%	4%
Stratification	7%	13%	7%	7%	13%	7%	13%	13%	7%	0%	13%
Control Charts	3%	15%	13%	10%	8%	4%	15%	8%	4%	10%	10%

TABLE V
TOP FIVE BENEFITS OF USING SEVEN QC TOOLS ACROSS CONTINENTS

Benefits	Code	Africa	Asia	Europe	North America	South America
Provide structure to problem solving	B	2	1	1	1	2
Help problem definition, measurement, and analysis	C	3	4	2	3	1
Aid problem solving	A	1	2	3	2	X
Assists in continuous improvement projects	E	5	3	4	4	4
Help improve product/service quality	D	4	X	5	X	X
Visibility of performance	P	X	X	X	5	X
Facilitates collection of data and presentation of data	L	X	5	X	X	3
Reduces cost of poor quality	M	X	X	X	X	5
Note " X" implies benefit is not listed in top 5						

and answer it incorrectly in a socially desirable manner. It was interesting to observe there was a disparity in the response to this question across the five continents. In total, 62% of respondents from the South American continent expressed the view that they are incorrectly using the basic tools of QC right first time (RFT) for over 20%. Moreover, on average 40% of respondents in the study expressed the view that that the incorrect application of the basic QC tools for over 20% (refer to Fig. 5). This misapplication can be due to lack of training or lack of understanding of what each tool's purpose is. Incorrect applications cost money and can prolong the root cause of an issue that affects quality.

The proportion test on incorrect tool usage was conducted between continents and also across sectors. Let $p1$ = proportion of incorrect tool usage in one continent, $p2$ = proportion of

TABLE VI
BENEFITS SECTORWISE

Benefits	Code	Manufacturing	Public Sector	Service Sector
Provide structure to problem solving	B	1	1	1
Aid problem solving	A	2	3	4
Help problem definition, measurement, and analysis	C	3	2	2
Assists in continuous improvement projects	E	4	4	3
Help improve product/service quality	D	5	X	X
Visibility of performance	P	X	5	5

Note: "X" implies that the benefit is not listed in the top five.

TABLE VII
CHALLENGES IN THE APPLICATION OF SEVEN BASIC TOOLS OF QC

Challenges	Code	Frequency
Lack of awareness and knowledge about the tools	C	191
Poor data collections methods	E	184
Lack of Training	A	182
Lack of management support	B	170
Not using the right tools at the right time	D	146
Lack of education on use of tools across entire organisation	H	146
Lack of understanding of each tool and its application	F	145
Lack of understanding of benefits of the tools	I	132
Lack of statistical knowledge	J	120
No motivation or drive to apply the tools	O	91
Poor attitude towards quality improvement	K	88
Poor/Bad organisational culture	N	84
Application of tools is an additional responsibility and I have no time	Q	71
Poor communication	M	57
Lack of teamwork	L	49
No need for the use of tools as we are different	P	24
The tools can be seen only for "manufacturing" or "production" departments only	G	21

TABLE VIII
CSFS FOR THE APPLICATION OF SEVEN QC TOOLS

Critical Success Factors for the application of seven QC tools	Code	Frequency
Management support and commitment	A	271
Having a continuous improvement program and integrating the tools within it	E	236
The seven tools provide a systematic and disciplined approach instead ofusing trial and error approach	I	200
Opportunity to participate in problem solving sessions or events	D	185
Communicating the benefits of tools across all levels of the organisation anddeveloping a culture	J	173
Opportunity to use the tools	C	172
Company-wide training	B	169
Sharing success stories and benefits	F	143
Recognition and Reward at the team level for the success on the applicationof tools	G	143
Creating the Sense of urgency by the senior management team for the use of tools in solving problem	H	140

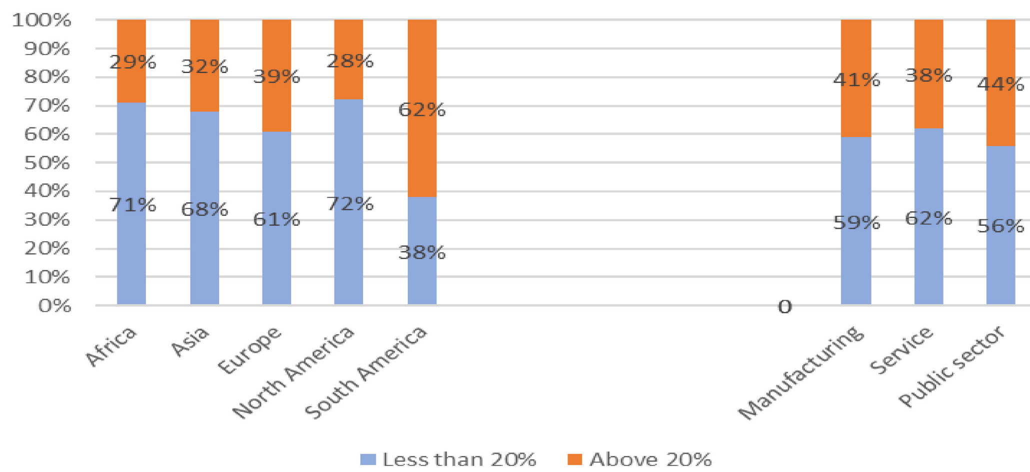

Fig. 5 Incorrect application of tools across continents and sectors.

TABLE IX
RESULTS OF MARASCUILO PROCEDURE

Contrast	Value	Critical range	Significant
p1-p2	0.032	0.237	No
p1-p3	0.097	0.244	No
p1-p4	0.014	0.304	No
p1-p5	0.329	0.279	yes
p2-p3	0.065	0.261	No
p2-p4	0.045	0.317	No
p2-p5	0.297	0.294	yes
p3-p4	0.110	0.237	No
p3-p5	0.232	0.205	yes
p4-p5	0.343	0.273	yes

$p1$ = Africa, $p2$ = Asia, $p3$ = Europe,
$p4$ = North America, p5 = South America.

incorrect tool usage in second continent. The null hypothesis was $p1$–$p2 = 0$ and alternate hypothesis was $p1$–$p2 \neq 0$. Since it involves multiple comparisons, the Marascuilo procedure enables us to simultaneously test the differences of all pairs of proportions when there are several populations under investigation [72], [73]. Sectorwise no difference was observed. Statistical difference was observed for incorrect tool usage above 20% continentwise. The statistical difference was observed and is given in Table IX.

The results were significant for comparisons for proportions for incorrect tool usage above 20%, between South America (0.62) versus Africa (0.29), Asia (0.32), Europe (0.39), and North America (0.28).

IV. Discussion, Implications, and Limitations

The basic seven tools of QC propagated by Dr. Kaoru Ishikawa have been around for nearly four decades. Although more than 85% of quality professionals have been trained in the basic tools for tackling quality and process related problems in organizations according to our global study, the authors argue that all quality professionals of the 21st century must be trained on these tools irrespective of the nature and size of the organization. The initial analysis of data has shown that the highest proportion of quality professionals who have not been trained on the basic seven tools of quality come from the South American continent. There was no significant difference in the proportion of quality professionals not being trained between the manufacturing companies and service and public sector companies combined.

This article makes an attempt to revisit the statement made by Dr. Ishikawa in his books that more than 95% of quality-related problems can be tackled using his seven original QC tools. However, the authors found the results of this global study significantly different from his claim in the 1980s and 1990s through his books [4], [6], [7]. The authors' findings from this research project suggest less than 25% (90/397 or 22.6%) of respondents are in favor of Dr. Ishikawa's statement. The findings of our study can be useful for organizations, which utilize both Toyota Kata and the Improvement Kata [48], [49], [74]. Toyota Kata is a scientific and proven way for companies to change from old-fashioned management by results to an efficient and better way. Practicing the improvement Kata can help in developing and utilizing the capability of everyone in an organization to repeatedly work toward and achieve new levels of performance. Rother explains how the Improvement Kata provides learners the means to experiment their way through obstacles and achieve tough goals [49].

In the past problem-solving efforts, the application of tools was aimed at problems in various stations on the shop floor with very little connectivity or interaction between the various end-to-end stations or assembly line process. In the past, we were not fully utilizing the historical data collected by various operators from various machines over a period of time across the plant. However, in the modern manufacturing world, we are taking the most of historical data collected from various machines and stations by various operators. For instance, Xu and Dang [75] have developed a digital cause and effect diagrams (CEDs), which can significantly improve the efficiency and effectiveness of a causal analysis. By using digital CEDs, quality problem solving (QPS) teams can save considerable time collecting information on the potential causes of problems. Although a digital CED cannot replace problem solvers and make causal analysis decisions, it can play an important role in supporting QPS-oriented decision-making.

Having a clear and shared understanding of the direction in the workplace creates a sense of purpose for the people doing the improvement work. Without a clear purpose, people have a much harder time to get motivated. It is essential to create a true understanding of the current condition of how people are operating their processes. Once people understand the current condition, it is important to establish the target condition and target performance. Having a clear target condition is very important for effective process improvements. Toyota will usually not start their improvement work until a target condition is clearly defined. In order to move from the current condition to target performance or condition, one should utilize a plan–do–check–act (PDCA) cycle of continuous improvement. The PDCA cycle is a systematic process for gaining valuable learning and knowledge for the continual improvement of a product, process, or service [49]. The authors would argue that the old seven tools of QC from Ishikawa can be integrated successfully into the PDCA cycle so that people on the shop floor in the case of manufacturing companies or front line personnel in the case of service companies can get the most out of problem-solving scenarios. As many manufacturing companies have been using the basic tools for continuous improvement scenarios, the authors believe that the integration of these tools into the PDCA framework can be much more beneficial to many public sector companies, such as local authorities or municipalities, higher education institutions, further education or colleges, police forces, and ambulance services. A study from Matsuo and Nakahara [76] has shown the positive impact of PDCA cycle on workplace learning, which is based on the concept of organizational learning. Finally, we would also argue that the PDCA cycle may also promote workplace learning by stimulating experiential learning theory as proposed by Kolb [77].

As Ishikawa's work was predominantly focused on manufacturing sector and within manufacturing, very little data evidence was shown about the extent of the application of his tools in different business functions within an organization. The authors extended his work to understand the extent of the use of such tools and found that the seven quality tools are least used in IT and finance functions across the continents. The findings also revealed that the Pareto analysis has been widely used in problem-solving exercises across all the five continents, whereas stratification and scatter diagrams were rarely applied. In all organizations, the seven tools were widely used in the production function, irrespective of the nature and continents participated in the global study. It was interesting to observe that control charts were more widely used than cause and effect analysis in the service industry. Some of the surprising findings from the study that needed further investigation include the following.

1) The use of stratification in R&D for both service and public sector companies was much higher than any other tool from the QC toolbox.
2) The use of histogram and check-sheet in the administrative function for public sector was higher than all other functions.
3) For the manufacturing sector, the use of seven tools of QC in finance and HR was lower than sales and marketing.

The findings of the study suggested that the benefits from the application of seven basic tools of quality across Europe, North America, and Africa were quite similar. Moreover, it was also found that the seven tools have proved to be beneficial in reducing the costs of poor quality for organizations in only South American continent. The authors also found that the top four benefits across the three clusters of sectors (manufacturing, service, and public sector) were identical. In terms of challenges in the application of the seven basic tools of QC, it was interesting to note that lack of team teamwork, lack of communication, no need for the use of tools as we are different, the use of seven QC tools is confined to production or manufacturing settings, etc., were the least reported challenges. Further analysis of data also revealed that there was just one challenge shared by all continents in the study: poor data collection methods. This means no strategy was in place for data collection so that the tools could be utilized for analysis and further decision-making process. In terms of challenges across the sectors, the reveals shows that the common challenges are lack of training, lack of management support, and lack of knowledge about the benefits of tools.

The analysis of CSFs has shown that two factors were common across all the continents; management support and commitment to the application of tools as well as having a continuous improvement initiative in place encourages the utilization of tools. In Africa, the analysis of data shows that the use of seven tools is not creating an opportunity for employees in problem-solving scenarios or events. At the same time, it was reported to be the only continent where team has been recognized and rewarded for the successful application of tools. From a research perspective, this was quite contradictory, and therefore, further data collection and analysis is required to understand the situation better. It was observed from the data that the two most common success factors across the types of sectors (manufacturing, service, and public sector) are: management support and commitment as well as communicating the benefits of tools at all levels of the organization and developing a culture of continuous improvement. Although recognition and reward system has been cited as a CSF for both manufacturing and service sectors, it was not cited as an important success factor according to participants from public sector organizations. Finally, the participants of manufacturing sector explicitly stated that the basic tools of QC provide a systematic approach to problem solving, whereas this was not the case with service and public sector organizations.

The final part of the global study was to understand if the quality professionals in organizations pick up the right tool RFT or not. Our findings suggest that 62% of respondents from the South American continent expressed the view that they are incorrectly using the basic tools of QC RFT for more than 20%. About 40% of the respondents from European continent expressed the view that they are using the basic tools of QC incorrectly for over 20%. The results were significant using the Marascuilo procedure for comparisons for proportions for incorrect tool usage above 20%, between South America versus other continents. This may be due to lack of effective training on seven quality tools, lack of trained consultants, data availability, in accurate assessment of quality issues in South American continent. In addition to the above, our study also reveals that on average more than 40% of quality professionals across the sectors are incorrectly applying the basic tools RFT with the highest of around 45% in public sector context.

One might wonder about the reasons for the misuse of simple and basic tools of QC in the modern manufacturing/service settings. McQuater *et al.* [3] argued that many companies ignore some of the most important CSFs for the effective applications of tools such as poorly designed training and support, poor measurement, and handling not using the basic tools as a part of developing a continuous improvement mind-set and culture, lack of framework for the systematic application of tools in problem-solving contexts and so on. Antony [78] explicitly highlighted some of the reasons for wrong application of tools in the context of problem-solving scenarios using some of the basic tools of QC including histogram. Many quality engineers use histograms without understanding the fundamental assumptions behind its use such as sample size and sampling. The focus of many training programs is on the use of software systems in creating these tools but not always on the assumptions and when and where to use them in problem-solving scenarios.

This research shares several managerial implications. First and foremost, the authors are questioning the original data derived from the work of Ishikawa in the 1970s and 1980s and its validity today in the organizations. Our study explicitly suggests that the original claim made in Dr. Ishikawa's books need to be revised for quality professionals in the 21st century. Second, the authors have explored the use of seven basic tools of QC in different functions of an organization such as IT, finance, HR, and marketing, and this aspect was never addressed in Ishikawa's original work. Third, the study also identifies the fundamental challenges in the application of basic tools of QC, benefits of these tools, and CSFs for the effective use of these tools in problem-solving scenarios. Finally, the study reveals the importance of choosing the right tool for the first time. It was interesting to learn that nearly 40% of quality professionals are not applying the basic tools correctly RFT and at this stage of the research, it was not possible to understand the impact of this problem. This would be a great avenue for the authors to explore further on this particular aspect in the near future via semistructured interviews with senior quality professionals as well as case study approach with a few selective companies across various continents.

Our study is limited in ways that can be addressed in the future research. First, the response rate from continents such as Asia, Africa, and North America were relatively low compared to South America and Europe. This would probably have some impact on the findings and robustness of the conclusions made about the continents. Second, interrater reliability of responses per participant organization could not be measured for the survey, which essentially measures the consistent of responses across an individual organization. Third, the authors could not look into the impact of organizational culture and types of leadership styles on the successful application of the basic tools of QC. Finally, surveys in general, cannot provide deep insights into various aspects of the research, and therefore, the authors like to pursue a number of semistructured interviews with selective quality professionals from various parts of the world as the next phase of this research project.

V. Conclusion and Agenda for Further Research

In this article, the researchers challenged Dr. Ishikawa's original statement that the seven QC tools solve 95% of quality-related problems and provided evidence to challenge this statement. This global study, the first of its kind to investigate Dr. Ishikawa's statement, demonstrated that less than 25% of participants across five different continents perceived that the seven tools of QC solved over 95% of quality-related problems. The research demonstrated that across continents that the Pareto analysis is the most widely used tool across all five continents. Check sheets and control chart were the most utilized tools in both manufacturing and service sectors with control chart surprisingly being utilized more than check sheets in the service sector. The least used tools were scatter diagrams and stratification. The seven QC tools were least utilized in IT and finance functions. Further research could analyze the factors around utilization of certain tools and whether the quantitative versus qualitative nature of some of the seven QCs tools affects user preference, ease of application and applicability to the problem being addressed. Also, the challenges around deploying the seven QC tools in functions, such as IT and finance could be expanded in further study.

In terms of the benefits of utilizing the seven QC tools and the CSFs there was commonality in the findings across both manufacturing and service sectors and across continents. Finally, 40% of quality professionals stated that they had used the incorrect QC tool "right first time" during problem solving. There is an avenue to explore the reasons for this misapplication further.

The reasons for this misapplication are not fully understood and can cost the company money and resources and are an avenue for further exploration. In summary, the global nature of this study and the relatively large response rate demonstrated the validity of the seven QC tools in problem solving in terms of the benefits of utilizing the tool. The study also demonstrated the consensus around the common challenges, benefits, and CSFs to applying the tools in organizations which were common across sectors and across continents. In terms of further research, a limitation of this research would be the lower response rate from continents such as Asia, Africa, and North America as compared to Europe and South America, and it would be interested to expand the study in these continents.

However, as a gap in the research, there is no framework in which to use the seven QC tools. Even within the DMAIC methodology, some of the tools are used in the measure and analyze phases, e.g., Pareto, histogram, check sheet, cause and effect, etc., but are not as relevant within the define and improve phrase. There is a need for better application and usage of the tools as part of a DMAIC type methodology. Consolidating the seven QC tools with the seven QC management tools is a further opportunity for study.

There is an opportunity to develop a more detailed exploratory research in the form of semistructured interviews or focus groups with different leading quality practitioners in the field to obtain further insights into the research questions addressed in this research. Also, there is an opportunity to explore the effect of organizational cultures (East versus West) and leadership styles (e.g., servant, participative, transactional, etc.) on the successful application of the seven QC tools. With the advent of Industry 4.0, it will be an opportunity to look at a quality curriculum and to see how problem-solving tools can be utilized with increased automated processes, simulations and other digital systems. The seven QC tools are on every quality training curriculum and there is an opportunity to create a more robust and usable curriculum.

Appendix A

Sectorwise Chi-Square Analysis

	Less than 50	50 to 80%	above 80%	Total
Manufacturing	84	107	72	263
Public	13	12	8	33
Service	53	38	10	101

sector * qualtprob Crosstabulation

			qualtprob			
			50 to 80	Above 80	Less than 50	Total
sector	manf	Count	107	72	84	263
		Expected Count	104.0	59.6	99.4	263.0
		Residual	3.0	12.4	-15.4	
	Pub	Count	12	8	13	33
		Expected Count	13.1	7.5	12.5	33.0
		Residual	-1.1	.5	.5	
	Ser	Count	38	10	53	101
		Expected Count	39.9	22.9	38.2	101.0
		Residual	-1.9	-12.9	14.8	
Total		Count	157	90	150	397
		Expected Count	157.0	90.0	150.0	397.0

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.305[a]	4	.001
Likelihood Ratio	19.610	4	.001
N of Valid Cases	397		

[a]0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.48.

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