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INQUIRY INTO THE USE OF QUALITY TOOLS FOR ROOT CAUSE ANALYSIS

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A B S T R A C T

There are many possible quality tools available for RCA and this research seeks to identify which quality tools are used by quality professionals specifically when performing an RCA. An anonymous survey was emailed to an organization's quality leaders at locations around the world. The survey asked the respondents to list the quality tools that they use when performing an RCA as well as the quality tools that they think everybody should know for RCA. The results were then statistically analyzed. The Ishikawa diagram is both the most commonly used quality tool and the most recommended quality tool for RCA. Five whys and is/is-not were also commonly used quality tools. This research identifies which quality tools are actually used by quality professionals in industry when performing an RCA. This information can be useful for organizations when selecting a limited tool set for RCA.

1. INTRODUCTION

A root cause analysis (RCA) is performed to determine the reason something happened (Gangidi, 2019) using a structured approach supported by the use of quality tools to find the root cause (Mahto & Kumar, 2008), which is the reason a problem or failure happened. The root cause may be masked by superficial symptoms, which are a sign of a problem, but not the actual reason for the problem. Once the root cause is identified, improvements can then be implemented to avoid a reoccurrence of the problem (Andersen & Fagerhaug, 2014).

There are many possible approaches that can be used, such as Lean Six Sigma, A3 reports, and 8D reports. However, there are commonalties across approaches. Each requires a definition of the problem, an analysis of the problem, the development and evaluation of solutions, as well as the implementation of solutions to ensure the problem does not reoccur (Mohaghegh & Furlan, 2020).

Quality tools are used as a part of the Six Sigma approach to quality improvement, where training is conducted in the use of quality tools. Alternatively, non-breakthrough level improvements can be achieved through the use of simple quality tools (Antony & Banuelas, 2002; Arsovski, 2023; Ceko, 2023.).

Quality tools are also used as a part of the 8D report problem solving methodology. An 8D report has eight steps, beginning with forming a team and ending with congratulation the team once the problem is solved. The fourth step is where an RCA takes place and typical quality tools used during an 8D include Pareto charts, Ishikawa diagrams, five whys, flow charts, and check

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sheets (Biban & Dhounchak, 2017), as well as is/is-not analysis and fault tree analysis (FTA) (VDA, 2018).

Another approach to RCA that uses quality tools is the A3 report, which originated at Toyota Motor Company. An A3 report begins with defining the problem through the use of a problem description and ends with implementation of the identified solution. There is also a step where the RCA is performed. There is a heavy use of graphical methods in A3 reports, such as simple graphs, flow charts, and control charts (Chakravorty, 2019).

Regardless of approach used, there are some common steps that are taken during an RCA. The failure or problem must be described and potential causes are identified. The actual root cause must then be found and solutions identified and implemented to prevent the problem from happening again. The improvements must then be assessed to ensure that they function (Andersen & Fagerhaug, 2014). This overlaps with a ten-step approach proposed by Okes (2009), where the problem is first defined, the process is understood, potential causes are identified, data is collected, data is analyzed, possible solutions are identified, a solution is selected for implementation, the solution is implemented, the effect of the solution is evaluated, and the change is then implemented across the organization. Regardless of approach used, an RCA also requires the use of interdepartmental teams with expertise from different areas available. During an RCA, potential causes must be identified and evaluated (VDA, 2018) and quality tools are often used to help with this.

This study seeks to identify which quality tools are actually used by those who perform RCAs. To achieve this, quality professionals in an organization were surveyed to determine which tools they use the most often.

2. LITERATURE REVIEW

According to Antony et al. (2021), Karou Ishikawa proposed seven basic quality tools that Ishikawa believed could solve 95% of all problems. The seven tools are cause and effect diagram, check sheet, control chart, histogram, Pareto chart, scatter plot, and stratification.

The basic seven quality tools are also sometimes known as the Old Seven Quality Tools, the Classic Seven Quality Tools, or simply the Seven Quality tools (Barsalou, 2017). Although there is much overlap in lists of the Seven Basic Quality Tools, there is also some disagreement between authors in regards to which tools to include in the Classic Seven Quality Tools. For example, Smith (2019) lists scatter plot, Pareto chart, Ishikawa diagram, check sheet, and control chart as well as flow chart and run chart combined. Oakes lists flow chart, Pareto chart, check sheet, Ishikawa diagram, scatter plot, and histogram as well as run chart and control chart combined (2002). Pescod (1994) describes the Classic Seven Quality Tools as control chart, check sheet, graphs, scatter diagram, Ishikawa diagram, histogram, and Pareto chart. Sreedharan et al. (2018) describe the exact same basic seven quality tools as Ishikawa's original list.

There are many quality tools with different uses and some quality tools may be usable for different purposes. Jayaram et al. (1997) identified eight overlapping classifications for quality tools consisting of graphical tools such as Ishikawa diagram, control chart, flow chart, Pareto chart, quality function deployment, and data presentation, companywide techniques such as auditing, benchmarking, quality circles, and quality costs, quality tools for data analysis, which include check sheet, sampling, and design of experiments. There are also quality tools for the identification of problems, which includes root cause analysis, brain storming, Ishikawa diagram, control chart, and nominal group technique. Decision making tools include auditing, benchmarking, and force field analysis. Quality tools for modeling include benchmarking, flow chart, and work flow analysis and prevention tools include Pareto chart, Failure Modes and Effects Analysis, fool proofing, and control chart. The final classification is creativity tools such as brainstorming, nominal group technique, and process decision program chart.

Ozgur et al. (2002) divided quality tools into only two categories, consisting of basic quality tools and advanced quality tools. Basic quality tools included check sheet, histogram, scatter plot, control chart, Pareto chart, and flow chart. Advanced quality tools included tree diagram, affinity diagram, Failure Modes and Effects Analysis, and matrix diagram. An alternative classification is offered by Jayaram et al. (1997), who classified five of the basic tools, Ishikawa diagram, cheek sheet, Pareto chart, control chart, and histogram, as statistical tools.

Tarí and Sabater (2004) provided three classifications of quality tools. The first consists of the seven basic quality control tools, which include scatter plot, Pareto chart, Ishikawa diagram, control chart, histogram, graphs, and check sheets. The second classification is the seven management tools, with systemic diagram, relations diagram, affinity diagram, matrix diagram, arrow diagram, matrix data analysis method, and process decision program chart. The final classification is other tools, consisting of sampling, force field analysis, questionnaire brainstorming, control plan, and flow chart.

An Ishikawa diagram may also be known as a cause and effect diagram or a fishbone diagram, with the later name being due to its resemblance of the skeleton of a fish. An Ishikawa diagram graphically depicts potential causes that can result in an effect. Often, the potential causes are generated during team brainstorming sessions and the causes may be grouped under labels such as man, material, machine, and method (Sarkar et al., 2013).

Cournoyer et al. (2012) presented an example of an Ishikawa diagram for the breach of a safety glove in a glovebox while the employee was handling radioactive material. The Ishikawa diagram had a branch labeled worker. Under the worker branch, there are two additional branches. One branch was workers are tired and that branch has the sub-branch workers do not detect cut, which has an additional sub-branch, worker exposed. The other sub-branch was radiation monitors at glovebox were blocked, with a sub-branch labeled worker did not self-monitor at glovebox, with a lower-level branch worker's skin exposed.

Control charts are used to statistically monitor the performance of a process. Both the position of the process mean and the variability between samples can be monitored. Data may be collected both as individual values, or as multiple values collected together in a sample. The values are plotted in the order in which the data was collected and control limits are statistically calculated and values going above or below the limits indicate a process is not in a statistical state of control. There are many types of control charts that can be used, with the correct type of control chart depending on the type of data collected (Adeoti & Olaomi, 2016).

A control chart was used by de Mast (2011) to investigate instabilities in electronic components. When looking at samples from 41 weeks of production, the control chart clearly indicated the week in which the problem began was the 29th week. In addition, the problem was found to only pertain to one product and not a different product that had a comparable design and production process.

A run chart is much like a control chart; however, statistical control limits are not used for a run chart. Instead, a run chart provides a simple means for observing the occurrences of values over time and can be used to detect potential changes in a process (Barsalou, 2017).

Thekkumpurath (2013) illustrates the use of a run chart for monitoring past due payments as part of a Six Sigma project. The y-axis listed payments past due and the x-axis listed dates. The run chart then listed the percentages of payments that were past due, with the run chart showing a lower percentage of past due payments than at the start of the run chart.

Quality tools may be used sequentially; for example, data may be collected by check sheets and then separated using stratification. Data is stratified by taking data from mixed sources and separating by source, such as machines and suppliers. This can be done during data collection by using check sheets that list the separate categories of interest (ReVelle, 2016). Once stratified, the data can be viewed using other methods such as run charts, control charts, or histograms, or Pareto charts.

An organization with failing power supplies stratified failures by location using Pareto charts and determined that one geographic region was experiencing the majority of failures. The region was then further stratified by state with one state found to experience far more failures than other states in that region. The power supplier failures were then further stratified by supplier and one supplier was found to have delivered twice as many failing power supplies as the other supplier (Kendrick, 2008).

There are multiple types of check sheets. A check sheet may actually be a list of items which are checked off after an action has been completed or an item has been checked. This type of check sheet is used to ensure required actions are carried out and also provides documentation that the action was performed and it is typically used to monitor improvement actions after a root cause has been identified and improvements have been implemented. Another type of check sheet is also known as a defect location check sheet or concentration diagram and it uses a graphical depiction of an area to mark where failures occur. A third type of check sheet is a simple list of failures or defect types with a tally mark representing each occurrence of the failure or defect (Barsalou, 2020).

A quality improvement team saved almost $200,000 by identifying inefficient labor as well as avoiding the need for rework and stopping process breakdowns through the use of check sheets for data collection. Employees were given check sheets with categories such as system slow, system not working, print issues, internet problems, downloading PDF problems, and phone problems and each employee was instructed to place a tally mark on the check sheet next to the appropriate category whenever a problem was encountered (Smith, 2019).

A histogram is used to graphically display the spread of values, which may make it easier to see relationships (Andersen & Fagerhaug, 2014). Olmi (2015) used histograms to compare the spread of values between the inner diameters of valve bodies from two different suppliers. The histograms showed that valve bodies from one supplier were skewed, while the other suppler delivered valve bodies with a more bell-shaped distribution.

Pareto charts graphically depict the frequency of occurrences to identify the problems which, if solved, would have the greatest impact (Villarreal & Kleiner, 1997). A Pareto chart was used by Morales-Contreras et al. (2021) to determine which of many problems in a restaurant to address first. The Pareto chart showed that the problem with the greatest impact was re-processing, followed by delays in delivering food, disorganized dishes, uncomfortable staff, and cleaning the same things twice.

A flow chart is an easy to create method for gaining a better understanding of a process. Flow charts are used to graphically depict the steps in a process using boxes with the name of the process step. The relationships between the steps is depicted using arrows (Chapman et al., 2011). In place of simple boxes, a flow chart may also use more complicated symbols representing process related actions such as the beginning or end of the process, decisions, delays, transportation, and process steps (Villarreal & Kleiner, 1997).

Uluskan and Oda (2020) presented an example of a flow chart of the assembly of ovens with 42 individual steps, starting with moving necessary parts to the assembly line and ending with packaging of the finished oven and moving it to the warehouse for storage. The use of a flow chart for problem locations is illustrated by de Mast and Kemper (2009), who described John Snow’s famous ghost map, which was used to pinpoint the source of a cholera outbreak in 1850s London by marking the map at locations where cholera occurred. The source was then localized to specific water pump, which once the handle was removed, stopped the outbreak.

Some authors simply list graphs as one of the basic quality tools (Tarí & Sabater, 2004; Pescod, 1994) and a simple graphical method is the box plot. The box plot displays data with a box in the middle, representing half the values from the data set. Lines, known as whiskers, extend outwards with asterisks used to identify potential statistical outliers (Smith, 2017). Box plots can be used to view one data set, or to compare multiple data sets, such as data from before and after a change, as demonstrated by Zwetsloot and Does (2015), who used a box plot as part of a Six Sigma project to compare the percentage of bounce of paid traffic between an old website and a new website, with the new website clearly having less bounce.

To find the underlying cause of a problem, 5 whys is used to dig down deeper to find the underlying reason a problem happened by asking “why?” five times (Murugaiah et al., 2010); however, five is more of a rule of thumb and the actual number of times why should be asked could vary (Mahto & Kumar, 2008).

Gangidi (2019) gives the example of five whys for a fixture column that would not lock in a required position. This was due to a screw that lodged in the tilting mechanism because it fell off. The screw fell because the magnet that should have retained it was weak and the magnet was weak because it had exceeded its working life.

In the 1970s, Japanese researchers introduced the world to the seven new management and planning tools consisting of activity network diagrams, process decision program chart, affinity diagram, interrelationship diagram, matrix diagram, and tree diagram (Anjard, 1995). Like the basic seven quality tools, there is also some differences in tools listed by authors with some including an arrow diagram in place of an activity network diagram (Rusly, 2018).

Affinity diagrams are useful for ensuring people contribute to the brainstorming and no one person is dominating the brainstorming, as well as encouraging the generation of creative solutions. To create an affinity diagram, ideas are generated through brainstorming and written down on note cards or sticky notes. The ideas are then clustered into comparable groupings and overall category label is given for each cluster of ideas (Bullington, 2018).

To better asses an organization’s quality system, one organization used an affinity diagram. First, 35 separate ideas were captured. Then, the ideas were sorted and consolidated in comparable groupings. One cluster was listed under the heading value chain and it contained activities related to the supplier, actions necessary to create the product, and activities related to customer needs. Another cluster was under the label support processes and included activities for the support of the management system, human resources, and support for the realization of products (Dias & Saraiva, 2004).

The matrix diagram provides a link between concepts by displaying one set of categories in the left-side column of a table with other categories listed in the top row. Commonalities are then identified within the matrix, such as who would have responsibility for certain activities (Anjard, 1995). Dias and Saraiva (2004) used a matrix diagram with positions listed in the column on the left-side column and activities in the top row. The relationship between positions and activities was then identified within the body of the matrix.

The interrelationship diagram is used to graphically display cause and effect relationships together with the links between multiple causes and effects (Fonseca et al., 2015). An interrelationship diagram can be used for high level strategic planning and provides an overview of the big picture (Levesque & Walker, 2007).

Tree diagrams are used to breakdown high-level concepts into their constituent elements with specific necessary tasks listed at the end of the tree diagram (Liu, 2013). For example, a tree diagram for the reduction of waiting time for inspection starts with the objective of reducing waiting time to under a day. The next lower level category is the improvement of supplier quality. To achieve this, communication with suppliers must be improved and the action to improve communication with suppliers is holding briefings with suppliers (Stocker, 1993).

The prioritization matrix is a matrix that lists options and criteria by which to judge the options. The options are assessed for how well they fulfill the criteria and are assigned a weighted value. The option with the highest weighted value is then selected as the best option (Liu, 2013). ReVelle (2010) illustrates the use of a prioritization matrix to select between five options while considering cost, time, resistance to change, and impact on the problem. Each consideration was assigned a numeric degree of importance and the options were rated in regards to how well they meet the considerations. The degree of fulfillment was then multiplied by the importance of the criteria and the results were then total to select the optimal option.

A process decision program chart is used for potential problems in a plan so that actions can be taken to avoid the identified problem (Fonseca et al., 2015). A process decision program chart was used for considering options when reopening a facility after the start of the Covid-19 pandemic. The top of the process decision program chart listed reopening the facility and below it were two levels of planning elements. One consideration was the modification of the facility layout and underneath this were multiple considerations including auditing to determine if there is sufficient capacity for social distancing. Underneath this level was a consideration of what ifs, including what if capacity was insufficient. The lowest level listed possible countermeasures, which were renting external office trailers and adjusting the operating schedule (Schvaneveldt & Neve, 2021).

An activity network diagram shows dependencies between the activities within a project and is comparable to a PERT chart. Circular nodes represent activities and the nodes are linked by arrows with activity completion time listed on the arrows. This information can be used to identify the critical path, which contains the activities that absolutely must be completed on time to avoid a delay in the project (Westcott, 2013).

The arrow diagram is a variation on the activity network diagram and it is used to indicate the flow of activities, such as tasks during a project (Liu, 2013). An arrow diagram resembles a Gantt chart and is useful for identifying where resources are needed and identifying potential bottlenecks in a process or project (Levesque & Walker 2007).

One problem may require the use of multiple tools to address it. This is illustrated by Chapman et al. (2011) who described the use of histograms, flow charts, and Ishikawa diagrams to analyze and solve the causes of variability in delivery times. A flow chart was used to gain a deeper understanding of the delivery receiving process, as well as to document the steps in the process. The actual variability in delivery times was documented in a histogram and an Ishikawa diagram was used to investigate causes of variability in delivery times. For other types of problems, a different assortment of tools may be required.

The use outputs of one quality tool may be useful as inputs for another quality tool. For example, failure data such as types of failure collected in a check sheet may be assessed using a Pareto chart. Alternatively, measurement data recorded in a check sheet can be visualized using a histogram (ReVelle, 2010). The ideas generated in an affinity diagram can then be transferred to an Ishikawa diagram resulting in an Ishikawa diagram created with the flexibility and creativity advantages of an affinity diagram (Bullington, 2018).

Fonseca et al. (2015) surveyed ISO 9001 certified organizations in Portugal and found that over 80% of respondents used basic quality tools, with the most commonly used basic quality tools being diagram graphs and check sheets. Service organizations also commonly used histograms and industrial organizations used control charts. Brainstorming was often found to be commonly used. Both service organizations and industrial organizations used basic quality tools; however, the use of more advanced quality tools tended to be used more often by larger organizations.

Sreedharan et. al. (2018)presented a study in which they found that the most commonly used quality tools in an organization where check sheet, flow chart, Failure Modes and Effects Analysis, control chart, flow chart, Plan-Do-Check-Act, and matrix diagram with the flow chart being the most commonly used of all followed by Design Failure Modes and Effects Analysis.

A study by Starzyńska (2014) found that the most commonly used quality tools for process performance problems such as defects, high process variability, and low process efficiency, are descriptive statistics with 20% of respondents using them, Pareto charts with 12% of respondents using Pareto charts, and capability indicators, which are only used by 10% of respondents. Alternatively, for supplier related problems, such as poor quality supplied material, 26% of respondents used check sheets, 17% used statistical quality, 13% used Failure Modes and Effects Analysis, and only 9% used Ishikawa diagrams.

In contrast, Tarí and Sabater (2004) conducted interviews with quality professionals in ISO 9001 certified organizations and found that only 20% used Ishikawa diagrams and 18% used Pareto charts. Graphics were used by 62%, 43% used flow charts, 40% used control charts, 31% used histograms, and scatter diagrams were used by 15% of organizations. Antony et al. (2021) found that out of basic quality tools used in organizations, the most commonly used quality tool was the Pareto chart followed by the Ishikawa diagram and then the histogram. Control charts and check sheets were almost tied and were followed by stratification and finally scatter plot.

Jayaram et al. (1997) conducted a survey of manufacturing organization directors identified through an American Society for Quality (ASQ) list. The authors received 313 responses from all 50 American states from organizations in various industries such as aerospace, food, defense, electronics, consumer products, and automotive industries. The authors found that basic quality tools for RCA consisted of Ishikawa diagrams and Pareto charts. Additional quality tools were used for purposes other than RCA, such as histograms as a part of inspection strategy, control charts and histograms for process control strategy, and flow charts for process improvement strategy (2010).

A survey found organizations practicing Six Sigma to use Ishikawa diagrams, control charts, and Pareto charts 100% of the time. This was followed by run charts, which were used by over 70% of organizations. (Antoney & Babuelas, 2002).

A survey of South American companies by Antony et al. (2021) found that the most commonly used quality tools were the Pareto chart, Ishikawa diagram, and histogram. An older survey of problem solving tools questioned 40 executives from industry on which tools they used the most. The survey had three classifications of quality tools, consisting of seven basic tools, seven new tools, and other tools. The survey found that 70% of executives used flow charts, followed by 67% using Ishikawa diagrams, 61% using Pareto charts, 48% using control charts, 36% using scatter plots, 25% using histograms, and no reported use of check sheets. The new management and planning tools most frequently used were arrow charts used by 48% of respondents, structure tree used by 14% of respondents and relationship diagrams, matrix diagrams, and activity network diagrams were only reported as frequently used by 1% of respondents. Out of other quality tools, brainstorming was used frequently by 79% of respondents (Ceridwen, 1992)

Ozgur et al. (2002) found that quality tools are used more often in ISO 9001 certified organizations, but ISO 9001 certification alone does not ensure correct use of quality tools. Tarí and Sabater (2004) found that the use of quality tools in organizations is sometimes hindered by lack of management support. The implementation of quality tools in an organization may also be confronted with employees' resistance to change. The use of quality tools in an organization cannot be simply mandated by an organization's management. Management must support the implementation and the employees require training in the use of quality tools (Sharma et al., 2017). Ishikawa originally envisioned employees being trained in the use of basic quality tools. This enabled employees to improve the quality of their own work output. It also helped contribute to Japan' rise to prominence in quality (Watson, 2004).

3. METHODOLOGY

A survey was sent to a global organization's email distribution list for quality managers. The recipients were asked to complete the survey and to forward the email to their subordinates in quality departments. There were over 30 people on the list and the total number of employees reporting to them exceeded 200. However, the response rate was 17.

All respondents had 4 or more years of experience, with 47.1% having more than ten years of experience. Almost half of respondents were engineers, 29.4% were managers, 11.8% were either senior manager, director, or above, 5.9% were technicians, and 5.9% selected none of the above. People in six countries respondents, with 41.2% Germany, 23.6% in Portugal, 11.8 % in both America and China, and 5.9% in both India and Portugal.

The survey questions consisted of:

- Is there one quality tool you use the most for rootcause analysis? Yes or no? If yes, please list the quality tool.
- On average, how many different quality tools do you use when performing a root cause analysis?
- Which quality tools do you use the most? Please list all quality tools that you typically use at least once out of every three root cause analyses that you are involved in.
- Which quality tools do you sometimes use? Please list all that you typically use at least once out of every four to eight root cause analyses that you are involved in.
- Which quality tools do you seldom use? Please list all that you typically use, but less than once per every nine root cause analyses that you are involved in.
- How many key quality tools do you think everybody should know for root cause analysis?
- Which key quality tools do you think everybody should know for root cause analysis?
- How many hours of quality tool training do you think every person involved in root cause analysis should have?

The results for seldom used quality tools, sometimes used quality tools, and the most used quality tools were combined and analyzed using a Chi-square goodness of fit test. The Chi-square goodness of fit test is used to determine if there is a statistically significant difference between observed values and the number of occurrences if all values occurred at an equal rate (Keller et. al. 1994).

4. RESULTS

There were 17 responses for the question pertaining to the one quality tool used the most during an RCA and 3 of the respondents answered with multiple quality tools. The Ishikawa diagram, Five whys, and is/is-not stood out as occurring more often. One respondent listed 8D report, which is an approach to RCA and not an actual quality tool. The results are shown in Figure 1.

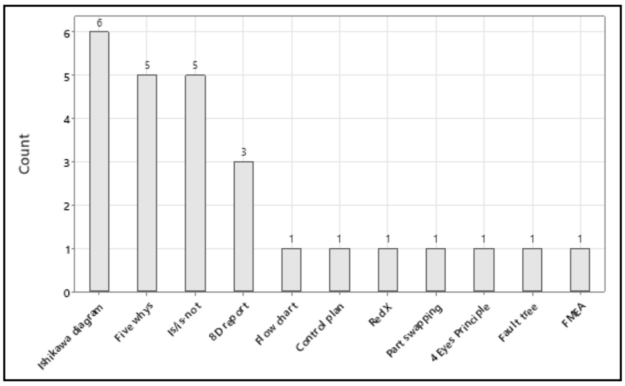

Figure 1. Most used quality tool

When asked how many quality tools are used for an RCA on average, three of the respondents listed more than one answer, consisting of "two or three," "maybe 4-5," and "3-4." Only the mean of each set of double answers was used and the mean was 2.8 and the median number of quality tools was 3.

The question on which quality tools are used the most resulted in the Ishikawa diagram listed the most with 11 occurrences, followed by five whys with nine occurrences. Five whys was closely followed by is/is-not with seven occurrences. The full results are shown in Figure 2.

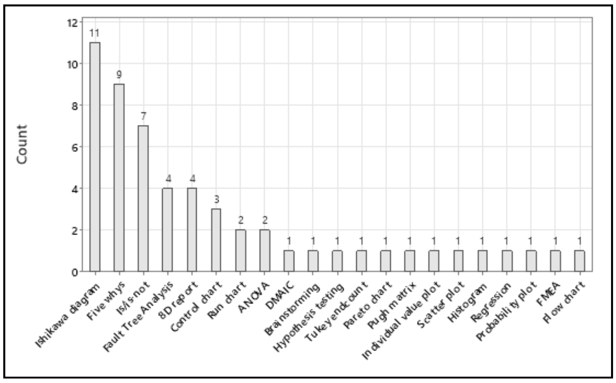

Figure 2. Most used quality tools

The mostly commonly given responses to the question pertaining to sometimes used quality tools were fault tree analysis and 8D report, which is not a quality tool (see Figure 3).

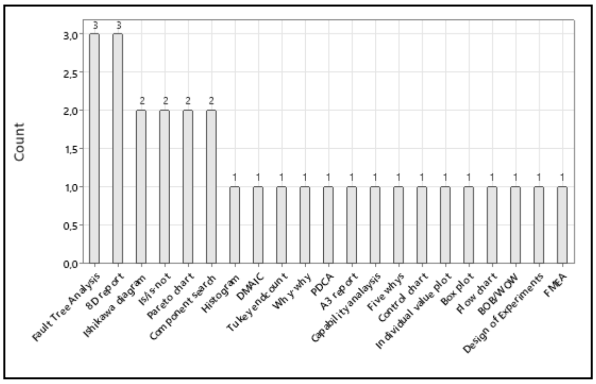

Figure 3. Sometimes used quality tools

The most frequent answers to the question on seldom used quality tools were the Ishikawa diagram and Pareto chart, as shown in Figure 4.

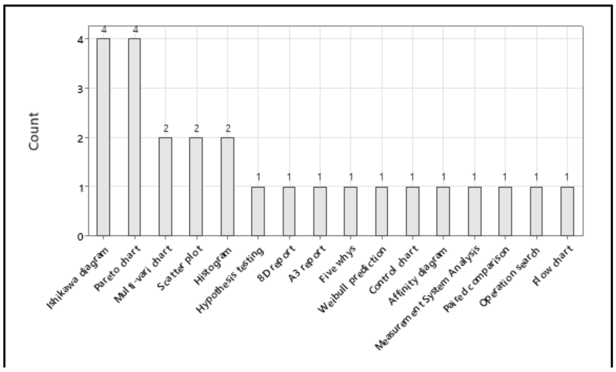

Figure 4. Seldom used quality tools

The responses for most used tools, sometimes used tools, and occasionally used tools were combined. The most commonly identified quality tool was the Ishikawa diagram with 17 occurrences, followed by five whys with 11 occurrences, and then is/is-not with 9 occurrences. The 8D report had 8 occurrences even though it is an approach to problem solving and not an actual quality tool. The results are down in Figure 5.

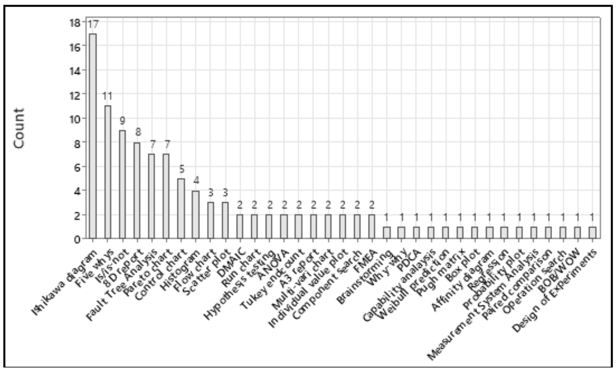

Figure 5. Quality tools combined

The survey results for quality tools that are frequently, sometimes and seldom used were combined and a Chi-square goodness of fit test was performed using Minitab Statistical Software. Table 1 depicts the results of the statistical test.

Table 1. Chi-square goodness of fit test results for frequently, sometimes and seldom used quality tools combined

Category	Observed	Test Proportion	Expected	Contribution to Chi-Square
Histogram	4	0.0285714	3.11429	0.2519
DMAIC	2	0.0285714	3.11429	0.3987
Brainstorming	1	0.0285714	3.11429	1.4354
Ishikawa diagram	17	0.0285714	3.11429	61.9125
Run chart	2	0.0285714	3.11429	0.3987
Is/is-not	9	0.0285714	3.11429	11.1235
Hypothesis testing	2	0.0285714	3.11429	0.3987
ANOVA	2	0.0285714	3.11429	0.3987
Tukey endcount	2	0.0285714	3.11429	0.3987
Why-why	1	0.0285714	3.11429	1.4354
Fault Tree Analysis	7	0.0285714	3.11429	4.8482
8D report	8	0.0285714	3.11429	7.6647
PDCA	1	0.0285714	3.11429	1.4354
A3 report	2	0.0285714	3.11429	0.3987
Capability analaysis	1	0.0285714	3.11429	1.4354
Pareto chart	7	0.0285714	3.11429	4.8482
Five whys	11	0.0285714	3.11429	19.9675
Weibull prediction	1	0.0285714	3.11429	1.4354
Multi-vari chart	2	0.0285714	3.11429	0.3987
Control chart	5	0.0285714	3.11429	1.1418
Pugh matrix	1	0.0285714	3.11429	1.4354
Individual value plot	2	0.0285714	3.11429	0.3987
Box plot	1	0.0285714	3.11429	1.4354
Flow chart	3	0.0285714	3.11429	0.0042
Affinity diagram	1	0.0285714	3.11429	1.4354
Scatter plot	3	0.0285714	3.11429	0.0042
Regression	1	0.0285714	3.11429	1.4354
Probability plot	1	0.0285714	3.11429	1.4354
Measurement System Analysis	1	0.0285714	3.11429	1.4354
Paired comparison	1	0.0285714	3.11429	1.4354
Operation search	1	0.0285714	3.11429	1.4354
BOB/WOW	1	0.0285714	3.11429	1.4354
Component search	2	0.0285714	3.11429	0.3987
Design of Experiments	1	0.0285714	3.11429	1.4354
FMEA	2	0.0285714	3.11429	0.3987
35 (100,00%) of the expected counts are less than 5				

N	DF	Chi-Sq	P-Value
109	34	137.284	0.000

All of the values had an expected count less than five, indicating that the Chi-square distribution is not approximating the normal distribution. Therefore, all occurrences of one were removed and the data was re-analyzed and the expected count for all values was again less than five. All occurrences of two were then removed and the data was re-analyzed. As shown in Table 2.

Table 2. Chi-square goodness of fit test results with quality tools with occurrences less than three removed

Category	Observed	Test Proportion	Expected	Contribution to Chi-Square
Histogram	4	0.0833333	6.5	0.9615
Ishikawa diagram	17	0.0833333	6.5	16.9615
Run chart	2	0.0833333	6.5	3.1154
Is/is-not	9	0.0833333	6.5	0.9615
Fault Tree Analysis	7	0.0833333	6.5	0.0385
8D report	8	0.0833333	6.5	0.3462
Pareto chart	7	0.0833333	6.5	0.0385
Five whys	11	0.0833333	6.5	3.1154
Control chart	5	0.0833333	6.5	0.3462
Individual value plot	2	0.0833333	6.5	3.1154
Flow chart	3	0.0833333	6.5	1.8846
Scatter plot	3	0.0833333	6.5	1.8846

N	DF	Chi-Sq	P-Value
78	11	32.7692	0.001

Differences are statistically significant with a P-Value of 0.001 and an alpha of 0.05. The quality tool that occurred the most was the Ishikawa diagram. This was followed by five whys, then is/-is not, 8D report, fault tree analysis, and Pareto chart. The remaining quality tools occurred less than would be expected if all quality tools occurred equally.

Study respondents were also asked how many key quality tools do you think everybody should know for root cause analysis. One respondent did not answer and three respondents gave a range; therefore, the mean value was used in these cases. The mean number of quality tools was 3.7 and the median was 3.0.

When asked which key quality tools everybody should know for RCA, the Ishikawa diagram was the top answer, followed by five whys, and then is/is-not. The results are depicted in Figure 6.

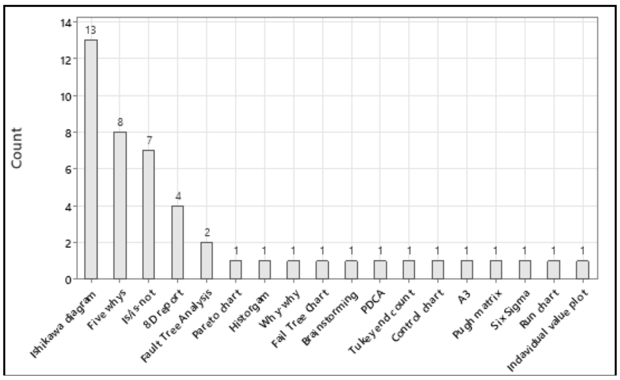

Figure 6. Quality tools everybody should know

The survey also asked the respondents about hours of training in RCA. Three respondents gave multiple answers such as “4-5” and 1 did not respond. The mean of the multiple responses was used for each set of more than one answer, where a range was given instead of a single value. The mean value was 17.3 and median was 12.0.

5. DISCUSSION

The study indicates organizations should conduct at least 12 hours of training in quality tools for RCA. The survey also inquired into both the single most used quality tool and the quality tools used the most. The top answers consistently included Ishikawa diagram, is/is-not, and five whys. The top quality tools listed were also Ishikawa diagram, is/is-not, and five whys when the often, sometimes, and occasionally used quality tools were combined. Organizations seeking a quality tool kit for RCA should consider these three tools for inclusion in the tool kit.

Respondents indicated that there should be 4 quality tools that everybody should know for RCA. Based on the study, these should be the Ishikawa diagram, is/is-not, and five whys. When results were combined, the 8D report, Pareto chart, and also placed highly, but not as high. However, the 8D report is an approach to problem solving and the Pareto chart is used for prioritization.

Next in order was the control chart, followed by the histogram. These two graphical methods should be considered for inclusion in any quality tool kit for RCA. The control chart is useful for viewing data in the order in which it was produced. A histogram is useful for viewing the spread of data and it has the advantage of being usable for data collected in time order and also random order; therefore, if only one additional quality tool is used, it should be the histogram due to flexibility.

6. CONCLUSION

This study used a survey to identify key quality tools used during a root cause analysis. Based on the survey, organizations should consider implementing 12 hours of quality tool-related training. The results also point to a pragmatic approach to organizational problem solving. Organizations should include Ishikawa diagrams, five why, and is/is not as essential quality tools in their problem solving tool kits. In addition to these quality tools, other tools can be considered such as control charts and/or histograms to provide graphical representations of process performance with visualization capability for key areas of change to gain insight into the root cause. Although not a quality tool, the 8D process and report provides the structure for managing RCA and communicating the results. Of course other tools can be considered, but these provide a very effective foundation, that based on the survey results, will be well-received.

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