FISH STO

Just the Facts

Today's technology makes it easier than ever to communicate complex concepts more clearly, which is why older, "analog" quality methods should be digitized.

The authors explore how digitizing one of the seven basic quality tools—the fishbone diagram—using mind mapping can significantly improve the tool.

Reimagining the fishbone diagram for the digital world

| by Gregory H. Watson and Ekaterina A. Spiridonova

The method behind the fishbone diagram—also called the Ishikawa diagram or a cause and effect diagram—is older than many of its users. It was first developed in an age of paper and pencil when graphics were largely hand drawn on paper or acetate foils.

Today, analysis is done on computers, and complex graphics are drawn using software. The opportunity to express ideas through graphical or visual representation has greatly expanded our ability to communicate complex concepts more clearly. Perhaps it is time to revisit the logical contribution of the fishbone diagram and find an improved graphical structure for communicating the same ideas.

Origins in value engineering

Interestingly, the fishbone diagram was inspired by lessons learned from World War II and the development of a method called value engineering.[1] Lawrence D. Miles originated value engineering during World War II while working in General Electric's purchasing department. He described it as a functional approach to value analysis that involved making choices about a material product's design that reduced the cost of delivering value. (See the sidebar "Functional Analysis in a Nutshell," p. 18.)

When value engineering and functional analysis were introduced to Japan in the mid-1950s, engineers in the Japanese Union of Scientists and Engineers (JUSE) were conducting research under a quality control (QC) research committee to determine how to develop a more coherent quality program based on logic and statistical methods that could be managed in their daily work environment. Value engineering was considered too complex for teams because it required a specially trained facilitator to apply the method, and it was confusing to managers who weren't familiar with the tools and techniques.

With adaptation, however, it was thought that the method could be useful and applicable for quality improvement to address the question: How do you develop a logical decomposition of the situation that frames the problem to be addressed? JUSE pursued two alternative approaches in parallel to simplify these methods so they would be more useful for Japanese engineers. These methods addressed how to graphically depict a systems breakdown of the combined functions of a product and the process by which it was produced.

According to Yoji Akao, quality function deployment (QFD) and the fishbone diagram have origins in the same problem considered by the JUSE QC research committee, which was chaired by Shigeru Mizuno and included Kaoru Ishikawa as a member. Mizuno and Akao approached the problem of how to decompose customer requirements into engineering functions and developed the concept of QFD to explain how the quality function is deployed from the voice of the customer to the voice of the engineer, and how it's realized in the production of an actual entity (part, product or software).

The fishbone diagram was inspired by lessons learned from World War II and a method called value engineering.

Ishikawa addressed a more basic question when developing the fishbone diagram. According to Noriaki Kano, the translation of "cause and effect diagram" isn't accurate because it should reflect the idea of a quality characteristics diagram—a decomposition of the quality characteristics that deliver the value of the whole actual entity that is represented—a process Ishikawa called stratification.[2]

Objective of the method

The question of identifying the components of a problem was first posed by Aristotle in his book *Categories*.[3] It's where Aristotle first proposed that initiation of any scientific investigation should be to decompose, or break down, the issue addressed into its component elements—a taxonomy of categories.

Graphically, the logical division or taxonomy that breaks down categories into distinctive rational subgroups may be represented by a tree diagram, in which each branch represents a mutually exclusive part or element of the higher level of abstraction, and the tree is permitted to branch until all potential divisions have been completely exhausted. This is why the consulting firm McKinsey calls this type of breakdown a "mutually exclusive, collectively exhaustive analysis."[4]

Expanding the functional descriptions and labeling

The fishbone diagram got its name because the completed diagram looks like a fish skeleton. The head of the diagram defines the purpose, problem or process output or result that is the desired effect. This effect is decomposed into a set of standard functional subgroupings that identify factors or functional elements that represent sources of potential causes of problems for the effect.

Ishikawa introduced the fishbone diagram in the 1960s.[5] He began by using four M's as generic labels to describe the core categories—materials, methods, machinery and measurement—and later extended the subgrouping categories to six M's, adding manpower and Mother Nature. Ishikawa also encouraged creativity in naming these categories to communicate more clearly to those who would be using the diagram. In explaining the fishbone diagram, he illustrated four ways to classify these labels.[6] We prefer a version that adds a seventh

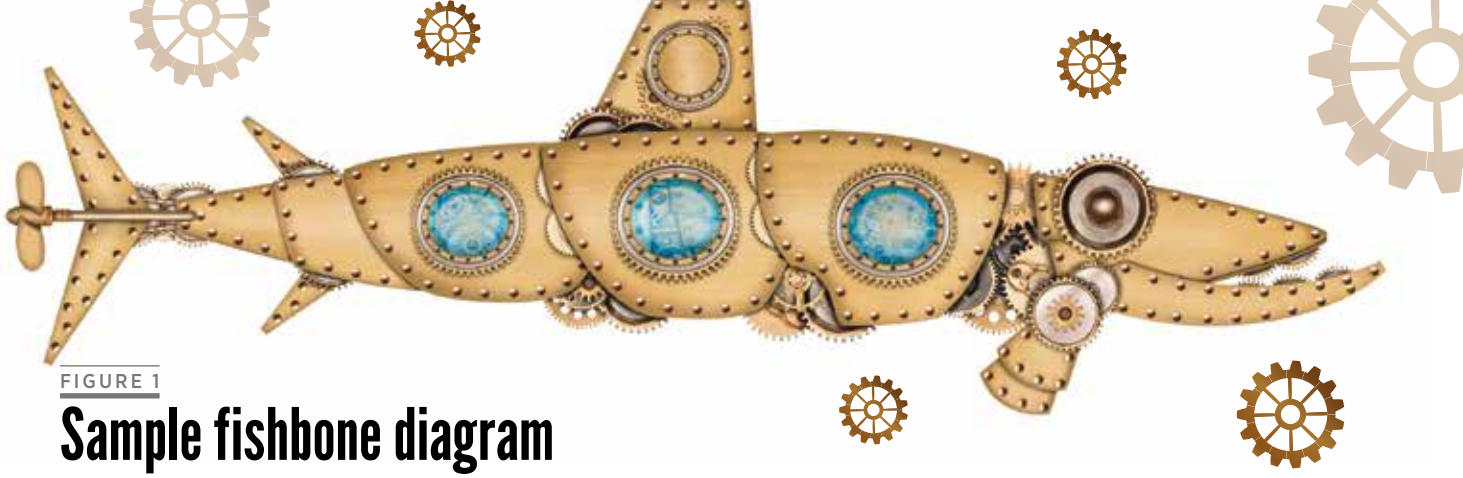
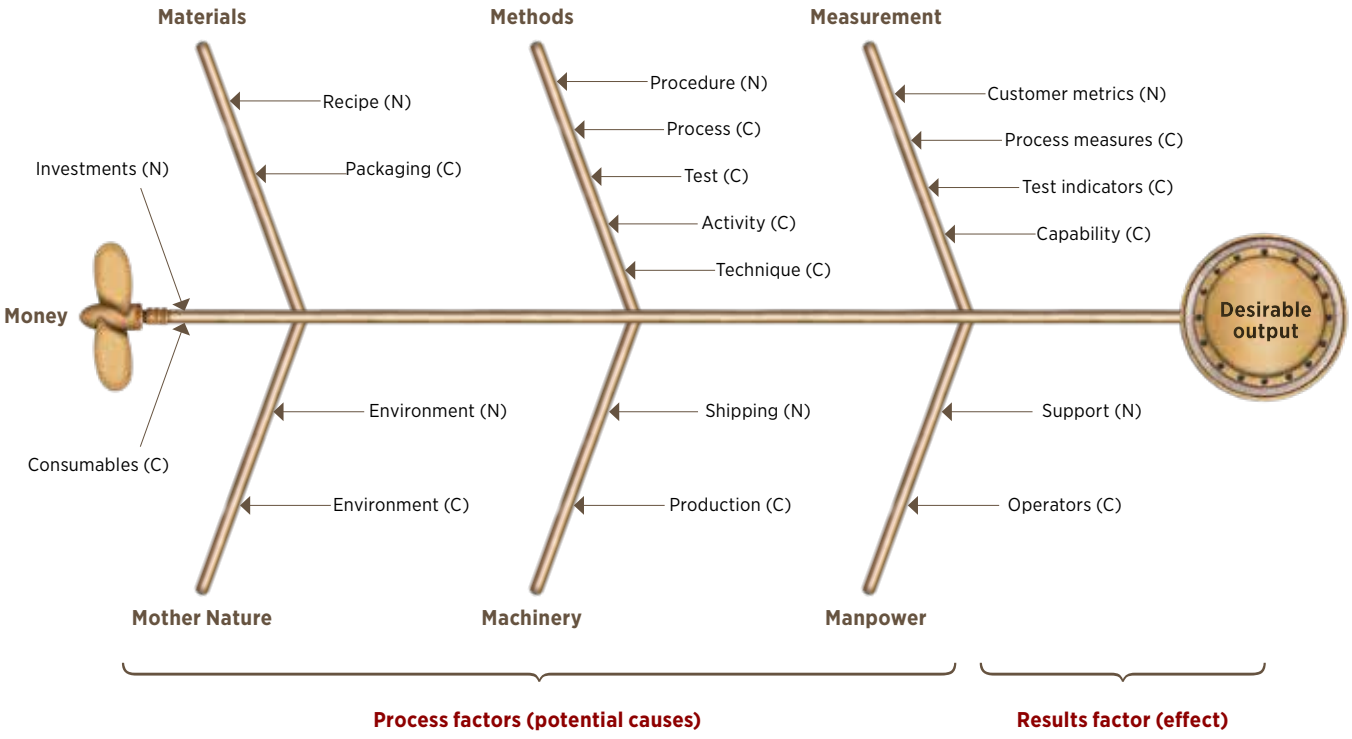


FIGURE 1

Sample fishbone diagram



***C** = controllable functions* ***N** = noncontrollable functions*

M—money—as a financial resource category. Thus, the seven M's in a comprehensive fishbone diagram are:

1. Materials—parts, ingredients and supplies.
2. Machinery—production-related equipment and software, as well as materials handling equipment.
3. Methods—procedures, techniques, critical decisions and vital processes.
4. Measurement—key indicators, measurement devices and key data capture or collection points.
5. Manpower—people and human resources with their associated training, skills and competence.
6. Mother Nature—environment and externalities.
7. Money—operating expenses and capital investments.

An example of the classical fishbone diagram is provided in Figure 1.

Variations of the fishbone diagram

Two variants on the classification of the rational subgroups have been applied to the basic fishbone diagram:

1. Identification of controllable and noncontrollable subfunctions in the decomposed diagram.
2. Identification of interrelationships among subfunctions related to multiple output Y variables that exist in each branch of the decomposed diagram.

The first application has been used for some time by process analysts. In this application, each subcategory function—or bone—is labeled to indicate the degree to which it influences the outcome. The following set of notations may be used to characterize the relationships of the

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Functional Analysis in a Nutshell

Functional analysis defines functions using noun-verb phrases that indicate the action that is being taken on an object. The classic example is the analysis of a pencil's functions. Functions are identified according to their dependencies, where primary functions deliver value in their output to customers, and secondary functions support the performance of primary functions. A primary function of a pencil, for example, is to make marks, while a secondary function is to support lead.

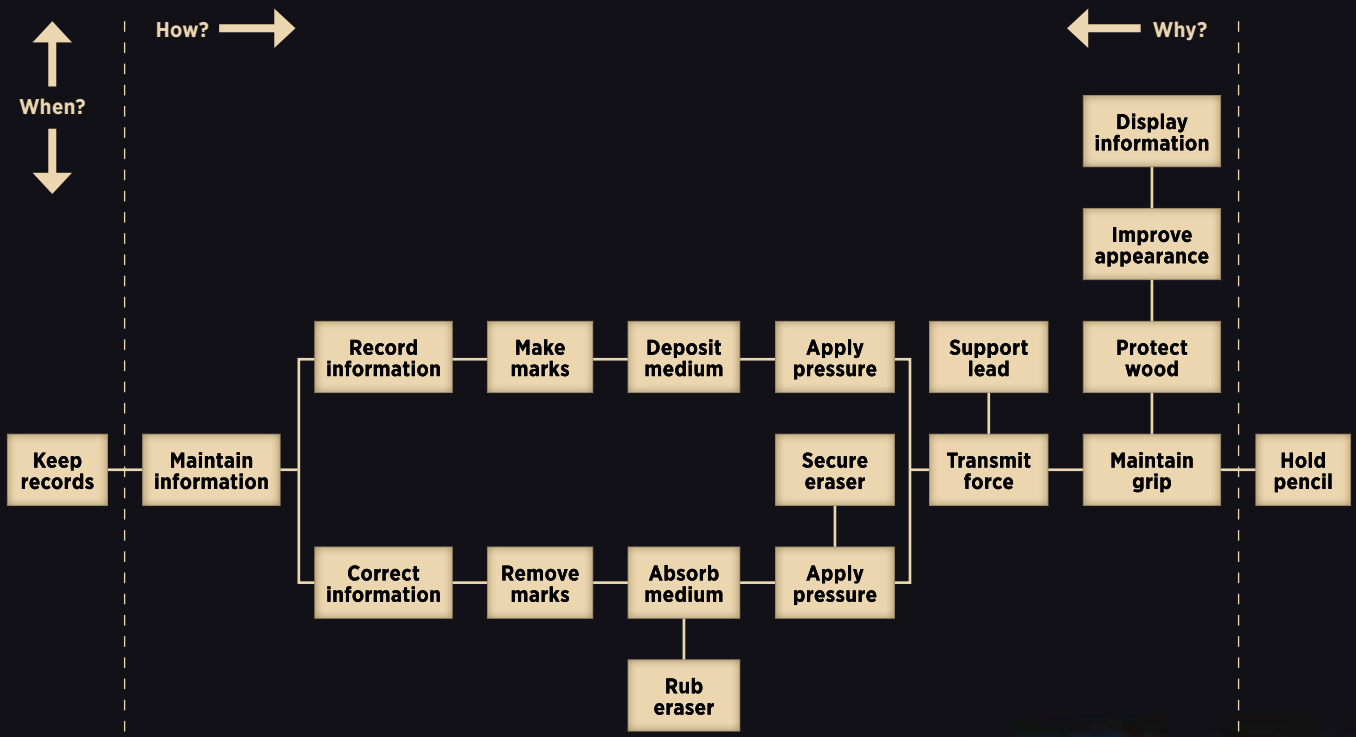
The method proposed by Lawrence D. Miles for decomposing a product into its functional components is the functional analysis system technique (FAST), which provides a multidimensional view of the product from either a marketing perspective (customer-oriented features) or a technical perspective (engineering design functions). (An example of a FAST diagram is shown in Sidebar Figure 1.)

The FAST diagram addresses questions such as why the function exists, how the function delivers its capability and when the function performs in terms of its causal sequence in the functional dependency (primary or secondary function).

In a FAST diagram, two viewpoints are merged into the graphical analysis—that of the customer and that of the engineer. A FAST diagram is read using these function questions to lead

SIDEBAR FIGURE 1

Sample FAST diagram for a pencil



FAST = *function analysis system technique*

through the sequence of steps, using the direction of the arrow for interpreting the basic meaning, as illustrated in Sidebar Figure 2.

The primary functions describe the use case of the customer and his or her application of a product (the customer needs), while the secondary functions enable the primary functions, or ensure a more acceptable or attractive product that meets customer wants.

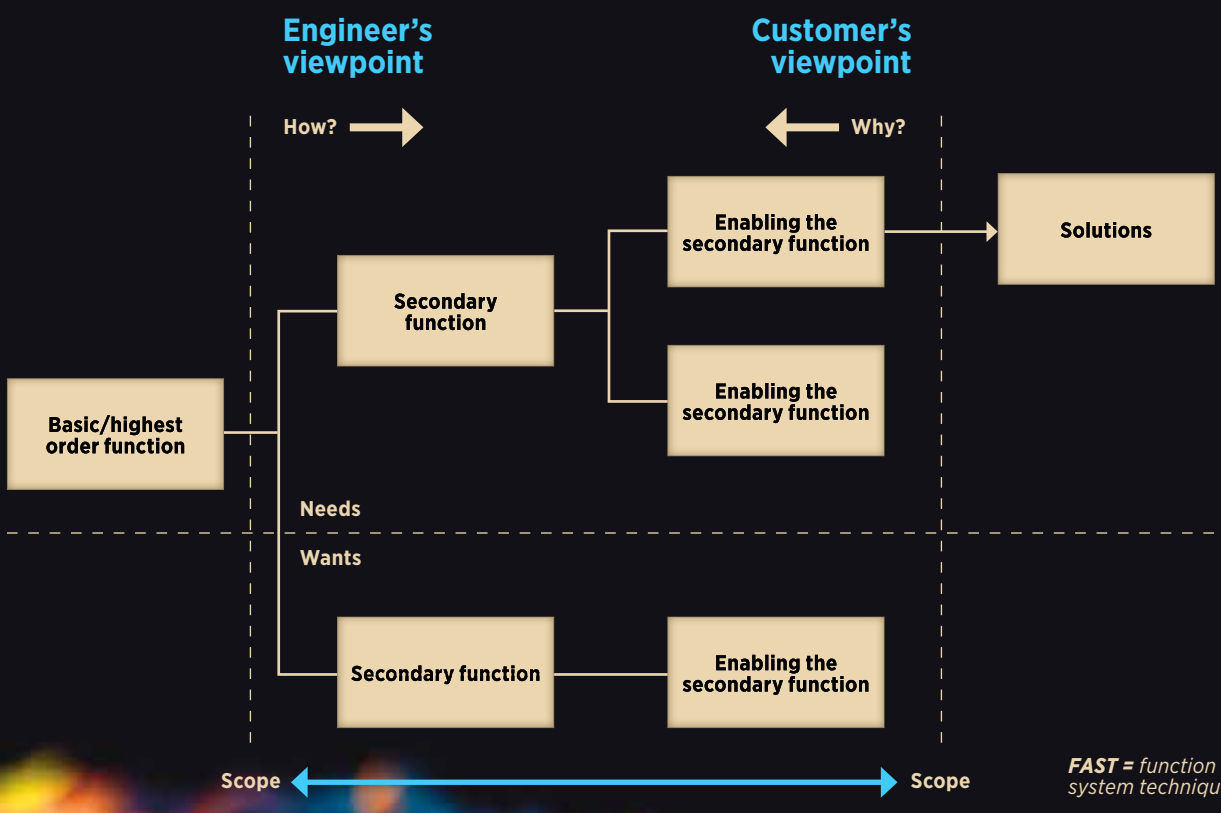
One problem with the FAST diagram is it has severe semantic difficulty when it's used for visualizing more complex systems. Most of the examples offered illustrate only simple products, such as a pencil or paper clip. Attempting to develop a FAST diagram for delivering a package, for example, causes severe problems in developing a rational architecture that makes common sense to the people working in the process, thereby limiting the utility of this method.

This probably is why Kaoru Ishikawa developed a simpler functional breakdown method—the fishbone diagram. It's also probably why Shigeru Mizuno and Yoji Akao developed a more complex way to describe customer requirements and translate them into concrete meaning for product design, development, and delivery—quality function deployment.

—G.H.W. and E.A.S.

SIDEBAR FIGURE 2

Logical structure of a FAST diagram



FAST = *function analysis system technique*

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individual X factors to the consolidated output Y factor, which typically is a product, service or process:

- **C = Controllable functions (signals).** These factors can be set or controlled during the process, service or product design or operation.
- **N = Noncontrollable functions (noise).** These factors are not easily changeable without adding new resources or redesigning the process, service or product.
- **M = Measurable.** These factors have an uncertain effect on the process but are most noteworthy because they could be measurable and may contribute to future performance knowledge.
- **X = Key performance function.** These factors are demonstrated to have a cause and effect relationship to the Y factor. They are measurable and controllable, and possess a mechanism that permits feedback to exercise regulation of the process.

The second variation on the basic fishbone diagram identifies multiple outputs of the process in the head of the diagram (multiple performance Ys for the process) and labels them using numbers. These numbers are tagged to each sub-bone that contributes to that particular output.

For example, if key performance variable outputs for the quality of a chemical process are viscosity, molecular weight and concentration, each would be assigned a unique number or code representing factors contributing to its resulting level of quality. These unique numbers or codes would be added to the label of each subfunction that contributes to this resultant performance. This variation may be used in combination with the classification of the bones relating to the nature of the controllability of that subfunction.

Applying a mind map

The basic problem with these static graphical representations of data is they can't demonstrate the interrelationships of rich data structures that occur in complex products or processes. One method that supports the identical graphical construct as fishbone diagrams is the mind map. It is a highly flexible method[7] created by Tony Buzan and has been broadly adopted for developing mental models, creative note-taking and documenting systems.

The mind map is designed to take a central idea and expand around it an ever-increasing structure that breaks down that idea into its rational subgroups. When the rational subgroups are structured using the seven M's—like the fishbone diagram—the construct is parallel to that of the standard graphic.

However, a big difference exists. Because the graphic is in a dynamic software package, it may be adapted using different conventions to include links to other graphical or data files as well as to specify other custom details. Figure 2 illustrates the logical structure of a fishbone diagram expressed as a mind map.

The essentials of mind mapping

Structured thinking develops a framework for unstructured problems. Having structure not only helps formulate the macro problem, it also identifies where to focus to gain deeper understanding of causal relationships. The purpose of stratification is to decompose an issue and expose the structure or mental model that must be solved.

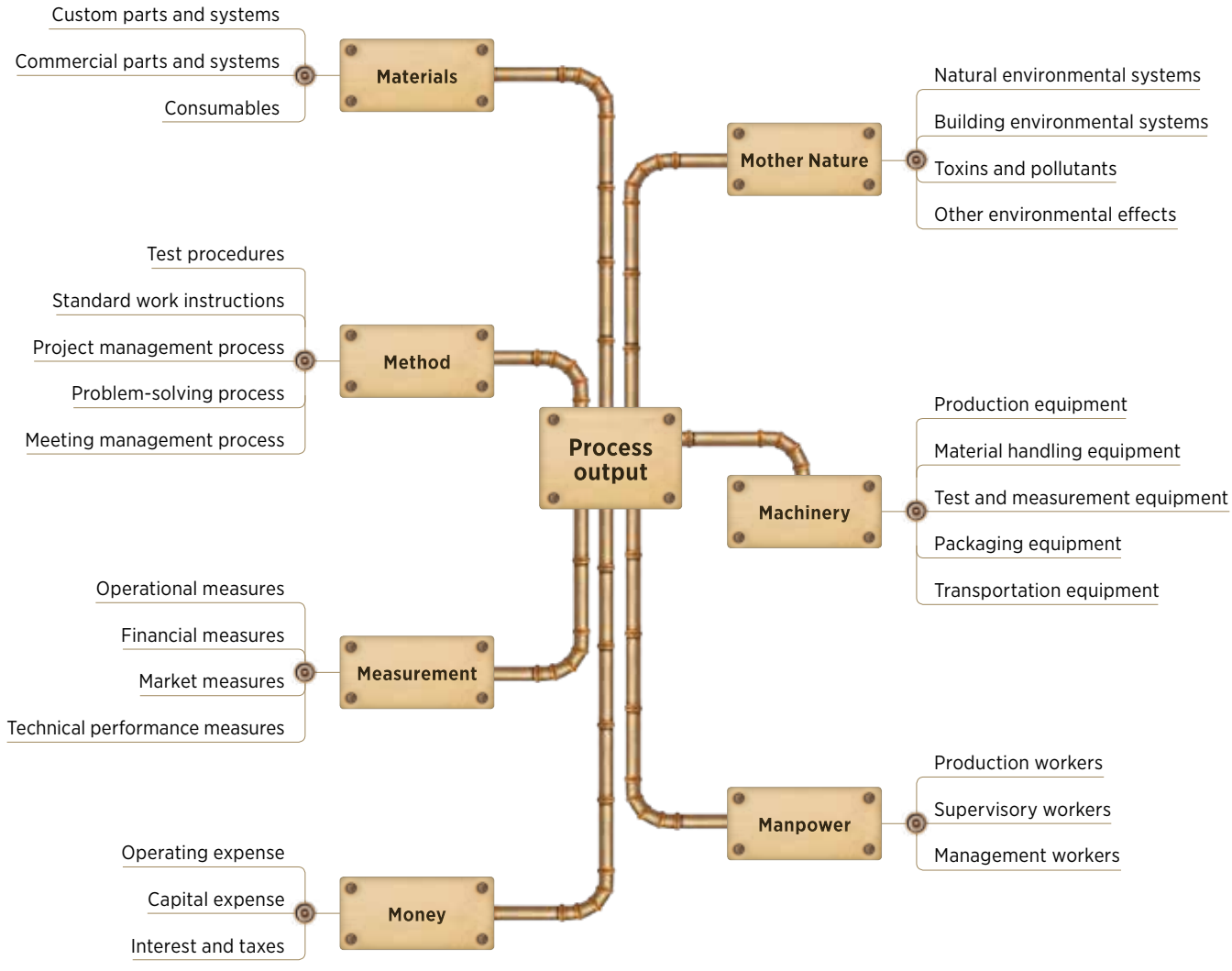
Mind mapping documents this mental journey, exploring ideas, associations and relationships to learn and visualize interrelationships, understand the conceptual structure and make sense from process flows, information links and work connections. Mind mapping combines output from the left side of the brain—which deals with logical structures—with output from the right side of the brain—which deals with creativity. It fuses words and pictures together to create a graphical picture to visually present thinking in a structured manner. This blends logic and creative thinking to more effectively learn about a subject under investigation.

Mind mapping enables process storytelling to explain how things actually work. Because mind mapping is graphical,

Ishikawa also encouraged creativity in naming these categories to communicate more clearly to those who would be using the diagram.

FIGURE 2

Sample of fishbone-like mind map



it allows our minds to process image data, which it does much faster than text or numbers. The fundamental logical tree structure helps organize ideas conceptually and presents a chain of ideas associated with a complex subject.

Mind mapping process

Mind mapping can be described using four process steps and a few rules. Mind maps can be drawn manually using a pen and paper, or created using a software program. The method begins by selecting a main idea upon which the graphical representation is concentrated.

Step one: Start with the main idea at the center and expand outward. The central idea becomes the hub of the diagram and focuses the visual image. The topic may be stated as an issue or problem statement, or as the name of a process deliverable.

Step two: Add branches to describe topics that amplify the central concept (in a fishbone type of mind map, branches

become the seven M's). The central concept is called a parent and the subbranch relationships are called its children. Each new level in the hierarchy describes a new generation of parent-child relationships. Each branch terminates when it can be described no further and there is no more valuable information to include.

Step three: Ensure the levels of abstraction flow from the general categories of things close to the model core outward to the specific details that are located further away.

Step four: Amplify the content of the mind map objects—embed videos, spreadsheets or PDF files into the process shapes to magnify the visual information with links to supplemental process data. Evaluate the rules for good mind mapping to ensure the most complete descriptions of the flows are provided.

Mind mapping rules

Visual rules. Use symbols, images, shapes and colors to distinguish related topics, types of thoughts or rational subgroups in the model.

Apply lines of varying color, size, style and dimensions, and arrowhead types to add meaning to categories of flows, such as information, commands, material, people, equipment, work, inventory, money and decisions, for example.

Avoid overcrowding images by using fewer than seven child subbranches for each parent topic. If additional information must be conveyed, another layer of hierarchy should be added.

Logical rules. Emphasize specific ideas by varying word case or size, or using different colors or font styles to separate ideas and topics.

Label each line to identify what flows and include a short description of the content of the flow using a standard thesaurus of terms that describe process elements in the larger system.

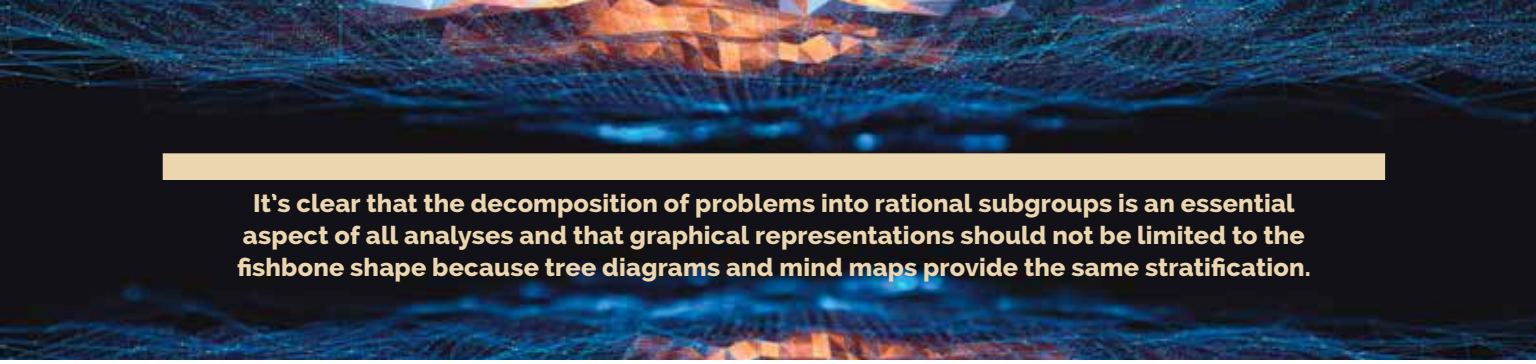
Mind mapping software

The mind map method is supported by software packages, such as Mindjet, Freemind, XMind, and Edraw. In addition,

TABLE 1

Mind mapping software

Name	Internet link	Price	User level	Platform
Bubbl.us	**https://bubbl.us**	**Free/$**	**Intermediate**	**Web-based**
Coogle	**https://coogle.it**	**Free**	**Basic**	**Web-based**
Edraw	**www.edrawsoft.com**	**$$**	**Advanced**	**Windows/Mac**
Freemind	**freemind.sourceforge.net**	**Free**	**Intermediate**	**Windows/Mac/Linux**
Freeplane	**freeplane.sourceforge.net**	**Free**	**Intermediate**	**Windows/Mac/Linux**
iThink	**https://iseesystems.com**	**$$$$$**	**Expert**	**Windows/Mac**
LucidChart	**https://lucidchart.com**	**$**	**Intermediate**	**Web-based**
Mind42	**https://mind42.com**	**Free**	**Intermediate**	**Web-based**
MindApp	**https://mindapp.com**	**Free**	**Intermediate**	**Web-based/Windows**
MindManager	**https://mindjet.com/mindmanager**	**$$**	**Expert**	**Windows/Mac**
MindMeister	**https://mindmeister.com**	**Free/$$**	**Advanced**	**Web-based**
SpiderScribe	**https://spiderscribe.net**	**Free**	**Intermediate**	**Web-based**
Text2MindMap	**http://text2mindmap.com**	**Free/$**	**Intermediate**	**Web-based**
WiseMapping	**http://wisemapping.com**	**Free**	**Basic**	**Web-based**
XMind	**www.xmind.net**	**Free**	**Advanced**	**Windows/Mac/Linux**



It's clear that the decomposition of problems into rational subgroups is an essential aspect of all analyses and that graphical representations should not be limited to the fishbone shape because tree diagrams and mind maps provide the same stratification.

Coggle is a free application available from Google. Because mind mapping software can emulate the output of a fishbone diagram and has many potential software options for extending the method, it should be seriously considered by quality professionals seeking to increase their ability to decompose processes and drill down to the root level of product or process structures.

Table 1 isn't meant to promote any specific software, but to list a compendium of mind mapping software that is currently available, including information about each application. Although many are open-source applications, some of the commercial products may be software as a service with minimal monthly fees or available for an individual license fee.[8]

Challenges for designing functional capability

New quality methods are more and more digitized, so we must adapt older methods to the digital age. The iconic Ishikawa diagram's transition to a digital form can be enhanced significantly using the mind mapping approach. Turning the functional labels into smart tags that are traceable in new product development documentation can increase the connectivity of design concepts and ensure that engineering analysis of the atomic level of designs is connected to the systemic level of customer requirements.

A challenge that the quality community must accept as digitization increasingly creeps into our body of knowledge is becoming proactive in developing digitized methods to replace the older analog methods that depend on manual manipulations. Questions to be considered in reengineering any of the basic quality methods include:

+ How will we employ the ubiquitous time stamps that exist in enterprise software to gain a better understanding of the flow of actual entities—such as products, customers and documents—across our business system?
+ How can we increase the information contained in our analyses by employing better methods that more rapidly inform about the performance status of our processes and the products and services that flow through them?
+ What changes should be made to the tools and rules by which we apply them in the conduct of quality analytics as real-time data are used in adaptive feedback loops for achieving maximum control?
+ What will be the role of the quality professional as a technical maestro—conducting, coordinating and facilitating this new way of working collaboratively with embedded IT systems?

A modest proposal

Ishikawa created the fishbone diagram to logically stratify an issue (product, process or problem) into subgroups that meet fixed categories, such as the M's. This investigation method was so basic that Ishikawa stated: "Without stratification, there can be no analysis or control."[9]

It's clear that the decomposition of problems into rational subgroups is an essential aspect of all analyses and that graphical representations should not be limited to the fishbone shape because tree diagrams and mind maps provide the same stratification. Thus, the class of stratification analyses represented by these types of diagrams should be called Ishikawa analysis, in recognition of the pioneering presentation of this generalized format by Kaoru Ishikawa. QP

REFERENCES AND NOTES

1. For more information on the history of value engineering, visit this article's webpage at qualityprogress.com
2. Kaoru Ishikawa, *Guide to Quality Control*, Union of Japanese Scientists and Engineers, 1960.
3. John Lloyd Ackrill, *Aristotle: Categories and de Interpretatione*, Clarendon Press, 1965.
4. Ethan M. Rasiel, *The McKinsey Way*, McGraw-Hill Education, 1999.
5. Ishikawa, *Guide to Quality Control*, see reference 2.
6. Ibid.
7. Tony Buzan, *The Mind Map Book*, Plume Publishers, 1993.
8. For more information on developing systems thinking models, visit https://thesystemsthinker.com.
9. Kaoru Ishikawa, *What Is Total Quality Control? The Japanese Way*, Prentice-Hall Inc., 1985.

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