Input for Chapter 17 of

*Global Innovation Sciences Handbook*

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# Chapter 17 Innovation Combination Methods - David Conley

This paper examines the simultaneous use of manifold methodologies for the purpose of producing innovative solutions to challenging problems. There are numerous paths through which problem solving and innovation can be pursued. Depending on the needs and goals of any particular analysis different methodologies can be used to take advantage of differing system and process attributes and approach solution generation from different angles. A variety of methodologies will be discussed with a focus on the strengths and weakness of those methods and how combining them can accelerate the process of innovative problem solving. Most of the methods described are in and of themselves complex processes which require study and practice in order to effectively apply them. Therefore, it is not my intention to teach each of the individual methods discussed below but rather to show how they can be combined into highly effective and targeted innovation processes. If you are interested in learning more about an individual methodology discussed in this paper, I urge you to seek out additional information from other qualified sources.

**Problem Solving Versus Innovation**

The term Innovation has been used extensively in business and technical organizations to communicate the interests and needs of their operations. In fact, many organizations use the terms "problem solving" and "innovation" interchangeably as if the solving of a problem automatically results in an innovation. This is not the case as innovation requires a solution type not created by most problem-solving efforts. Unfortunately, most organizations do not have a solid understanding of what the word "innovation" really suggests or what its pursuit entails. According to The American Heritage Dictionary, New College Edition, *innovate* is defined as: "to begin or introduce something new; be creative." This definition is of course correct in the general usage of the word, but it lacks the detail required to properly guide interested parties in its quest. Among experts in the field of innovation a more detailed and exact definition is utilized and provides general guidance to the innovation practitioner. "From the engineering perspective, creation of a new invention (innovation) always manifests as the full or partial overcoming of a technical contradiction (limiting situation)." [1] Rephrased, an innovation is an advancement that transcends a limiting situation within the system under analysis. Another way to describe these limiting situations is to refer to them as *contradictory requirements* within a system. Figure 1 provides several examples of system limiting situations, which can also be referred to as contradictory requirements. For example, the first example is in relation to the size of the engine in a car. The bigger the engine the more power it produces but also the more fuel it consumes. Therefore, a car needs both a large and small engine simultaneously. This is a contradictory demand of the system called engine. Solving this engine problem with a system that produces both high power with low fuel consumption would be an innovative solution because it meets both contradictory demands simultaneously. It is important to note here that while all three examples in Figure 1 involve contradictory requirements around the parameters of size or quantity, any system parameter could be at play including, but not limited to: weight, speed, volume, density, and strength. Knowing that a contradictory situation must be solved in order to create an innovative solution we now understand the importance of incorporating contradiction resolution methods into our problem-solving processes if we

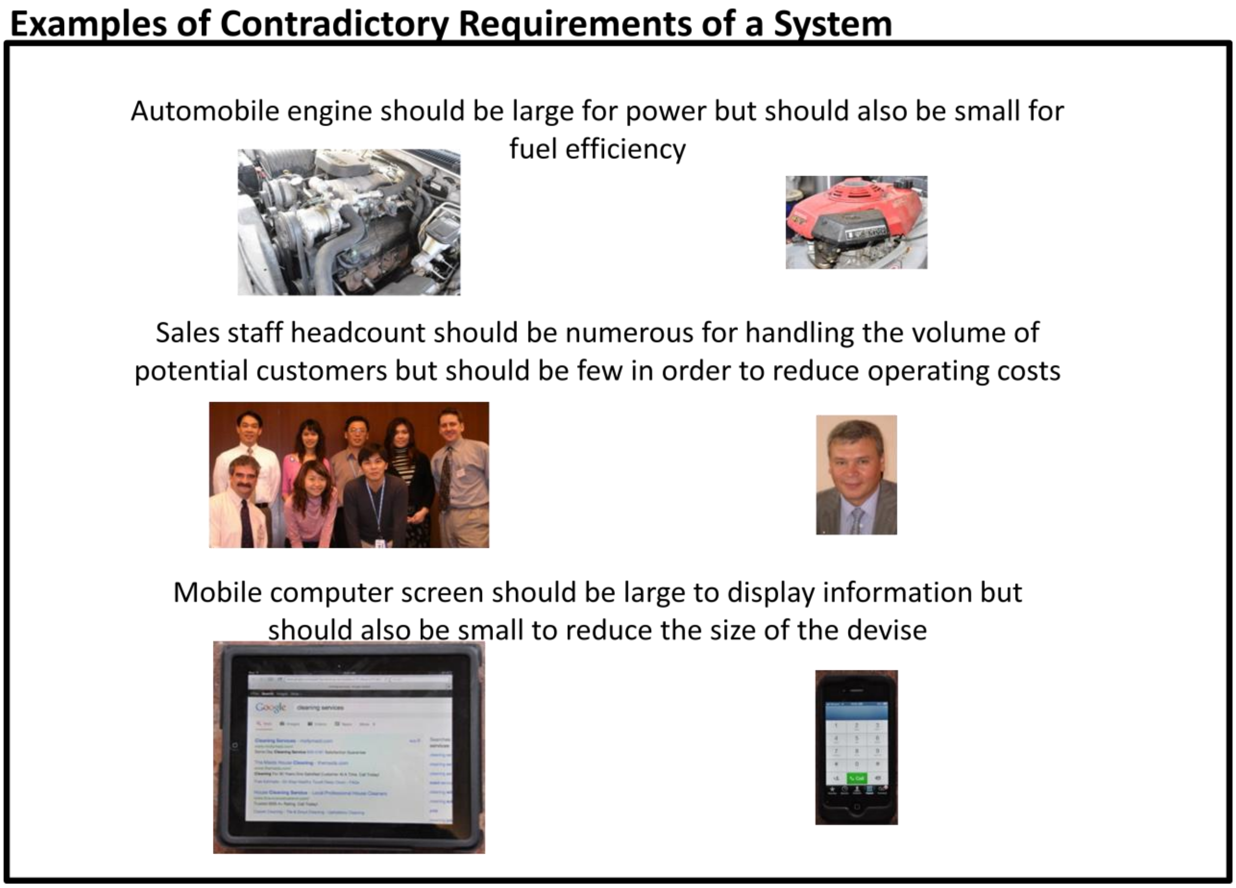


Figure 1

indeed are seeking innovation.  Therefore, innovative problem solving is a sub-set of problem solving in that a solution must resolve a limitation in the system under analysis in order to be an innovative solution.  However, in many situations solutions are generated that indeed solve a problem but do not resolve any system limitations while doing so.  Therefore, if a workable solution is generated then a problem has been solved.  If that workable solution also happens to resolve contradictory requirements (refer to Figure 1) of a system parameter, or attribute, then the solution can also be considered an innovation.   Here in lies one of the weaknesses of most every problem-solving technique currently in use today; almost none of the popular methodologies address the issue of contradiction identification and resolution.  Therefore, they do not regularly drive innovative solutions, at least in so far as the technical definition of "innovation."  This is not to say that an innovative solution can never result from one of the prevalent problem-solving processes but since the goal is systematic and repeatable innovation generation, occasional success is not acceptable.  A second problem with the most popular problem solving processes is that while they all have a step which calls for "creating a solution" to the problem at hand there are few, if any, algorithms or tools within the processes by which to generate those solutions.   In practice most expert problem solvers would agree that the prevalent problem-solving methods offer varying combinations of strengths and weaknesses.  If chosen wisely different problem-solving methods, with complimentary sets of differently focused strengths, can be combined to create a solid, useful, and innovative process.  Combining complimentary methodologies can result in fluid and well-rounded processes that provide effective tools and direction beginning with the initial problem identification step all the way through the verification of the implemented solutions. In the remainder of this paper I will refer to methodologies as problem solving processes if they at least support the solution generation process. Further, I will only refer to methodologies as innovation if they support the generation of solutions that are aimed at resolving contradictory system requirements

**More Detail on Defining Contradictions**

Let us take a few minutes to better define what a *contradiction model*, or the modeling of a limiting system contradiction, looks like. As an example, suppose that a wireless phone company needs a significant amount of equipment in order to improve the system's coverage area, but the company also wants very little equipment because it is expensive. Generally speaking, there are two boundary conditions, existing at opposite ends of a continuum, that define the range of available solutions to this problem within the restrictions set forth by the existing system design. In other words, based on how our fictitious wireless phone service provider's technical systems are designed there are two extremes defined by the current system limitations and therefore the solution can only exist somewhere between them. Figure 2 shows these two extremes. In situation one of Figure 2 the amount of wireless network equipment is at a maximum (large blue circle). This large amount of equipment drives two results: first is the cost of the system (large green circle on the left) which is very high and therefore represents a bad, or undesirable, situation and second is the performance, or effectiveness, of the system (large yellow circle on the right) which is excellent and therefore represents a good, or desirable, situation. In situation two of Figure 2 the amount of wireless network equipment is at a minimum (small blue circle). This small amount of equipment drives two results: first is the cost of the system (small green circle on the left) which is very low and therefore represents a good, or desirable, situation and second is the performance, or effectiveness, of the system (small yellow circle on the right) which is poor and therefore represents a bad, or undesirable, situation. Therefore, the amount of equipment needed for services is in conflict with the need to minimize the amount of equipment for the purpose of controlling costs. On one hand the company wants a large amount of cell towers, repeaters, and switching circuits and on the other hand the company does not want to have to pay for any equipment at all. This represents a contradictory requirement that serves as a system limitation. So, the problem to be solved is how can the company spend very little on network equipment but have the system perform as if there is a substantial amount of equipment in operation? In order to solve this problem with an innovative solution it is necessary to resolve the limiting system contradiction. The abstract model of such a solution is shown in Figure 3. In this diagram the solution, which is not necessarily just based around equipment quantity, is shown as the "unknown" solution state shown as a white circle. The as of yet unknown solution must result in the best of both worlds as reflected in the two related predecessor contradiction models (Figure 2). First the solution should be relatively inexpensive (small green circle at the left in Figure 3) and therefore represents a good situation and second the solution should have a high level of performance (large yellow circle at the right in Figure 3) and therefore also represents a good situation. Any solution that simultaneously meets the inexpensive and high-performance requirements of the abstract solution model above will indeed be an innovative solution. If you recall from the previously listed definition above, "an innovation is ...... that transcends a limiting situation

**Conflicting Situations Graphic**

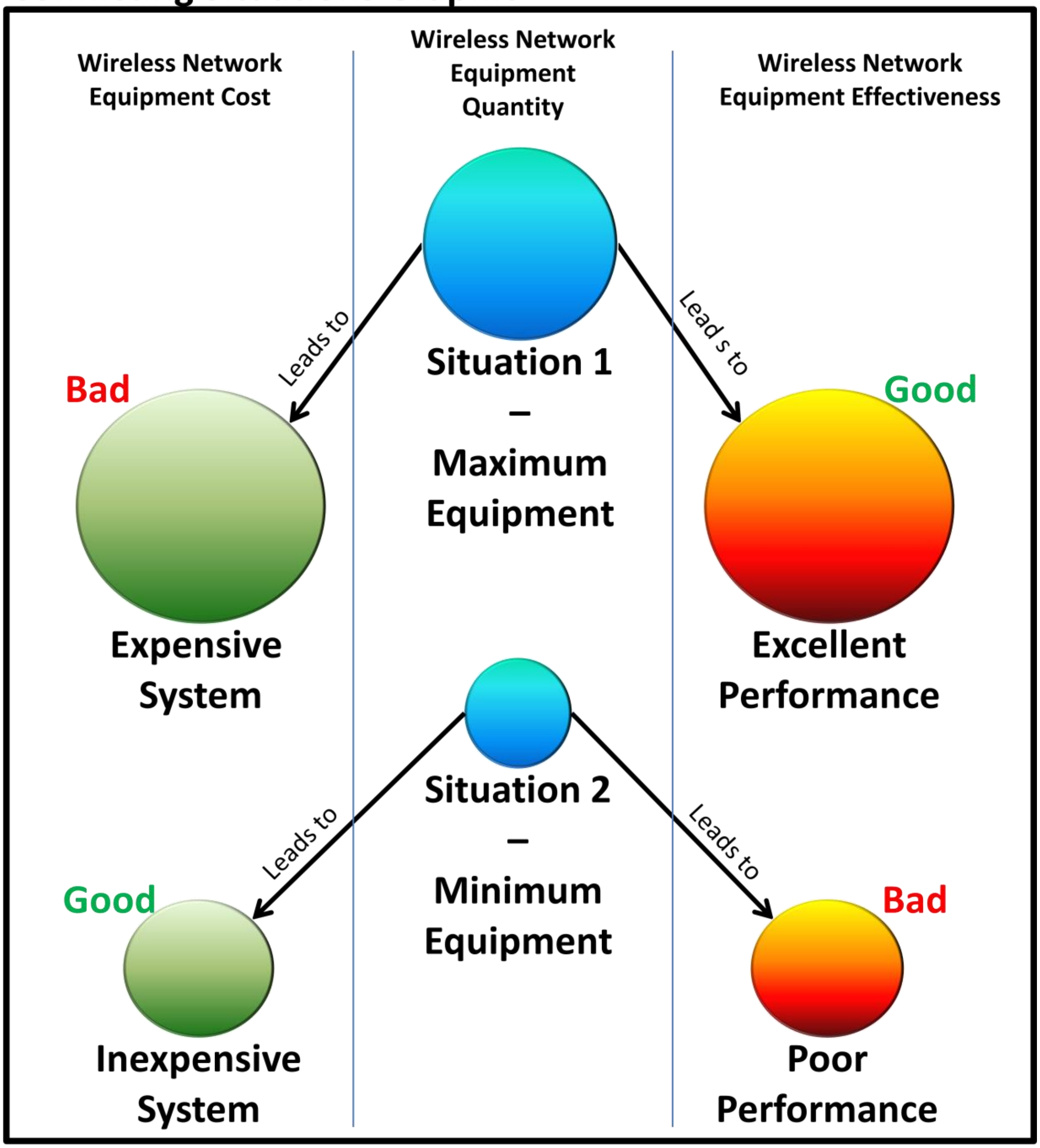


Figure 2

## Conflicting Situations Graphic

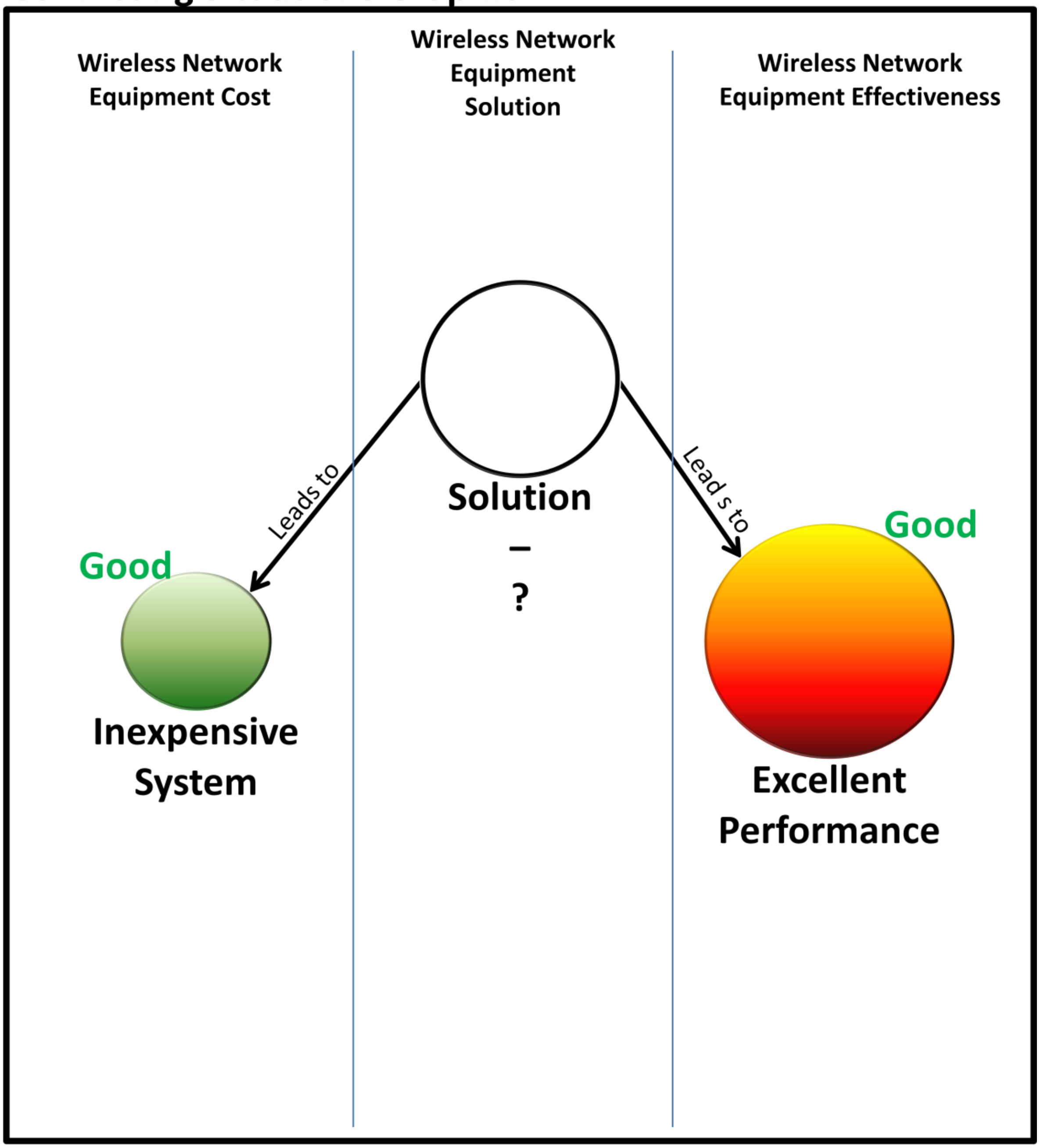


Figure 3

within the system under analysis," in order to create an innovative solution it is necessary to resolve the contradictory requirements around the parameter of equipment quantity. How can the system contain substantial equipment, in order to support the need for wireless services, and very little equipment, in order to control costs, simultaneously? The purpose of this example is necessarily for driving to a solution but rather to demonstrate what contradictory requirements and abstract contradiction resolution models look like. However, quite simplistically one solution could be to design mobile phones (i.e., Smart Phones) with repeater capabilities so that the collection of phones in the network are orchestrated to also act as the network itself.

**Combining Methods**

Unfortunately, it is not always obvious as to what the contradiction is in a system that needs resolving. Further, most organizations have preferred problem-solving methodologies in use within their operations. The methods that have been previously accepted by an organization have the obvious benefit of already being familiar to, and in use within, the organization. Additionally, the wide variety of problems solving methods in use today can provide unique capabilities and insights to the problem solver. For example, Six Sigma incorporates rigorous statistical analysis methodologies which can help define the problems, and measure their impact, plus support the evaluation as to whether the "solution" did indeed improve the situation. Lean (a.k.a. Toyota Production Process) provides an excellent framework by which to help us focus on the various types of waste that can be found in an operation or process. The Plan-Do-Study-Act cycle helps the user to consider important aspects of the problem-solving process. Root Cause Analysis facilitates the discovery of the fundamental causes of a problem by allowing a look beyond the effects that often mask the true problem sources. However, none of the aforementioned methods provide any resources, or algorithms, designed for the generation of actual solutions, innovative or otherwise. So, this leaves us with the question; which methodology is best suited to fulfill an organization's problems solving and innovation needs? Actually, there are no individual methods that fulfill all problem-solving needs. In reality, whether problems solvers realize it or not, multiple methodologies are employed in conjunction whenever problem solvers analyze issues and create solutions. Observations during my career have revealed that the most common practice is the usage of a problem identification method (i.e., Lean, 6 Sigma, Kempner-Trego, etc.) followed by the use of the standard fall back of brainstorming as the solution generation vehicle. This reality demonstrates that at the very least problem solvers utilize two methods when analyzing issues and generating solutions. I propose that the most effective advancements are indeed achieved by way of combining methods and the best combinations are dependent upon the traits of the organization solving the problems and the type of problems that need to be solved. Dr. Craig S. Flesher, author, academic and Chief Learning Officer of Aurora WDC, stated that "utilizing a purposefully sequenced combination of multiple analysis and problem solving methods is typically the best way to create effective and actionable results in today's complex world of business and technology."

**The Problem-Solving Path**

How do humans generally solve problems? The complexity of our innate problems solving processes might surprise you, especially since that for most problems we encounter the process is executed somewhat unconsciously. The complexity lies in that when we solve problems, we move through several problems modifications steps in generating a solution. The Problem-Solving Pathway shown in Figure 4 demonstrates the generic problem-solving process we naturally use when generating solutions to somewhat easy problems. For example, if the slamming of the barn door scares the livestock, we would quickly understand that it was necessary to keep the door from being blow shut by the wind

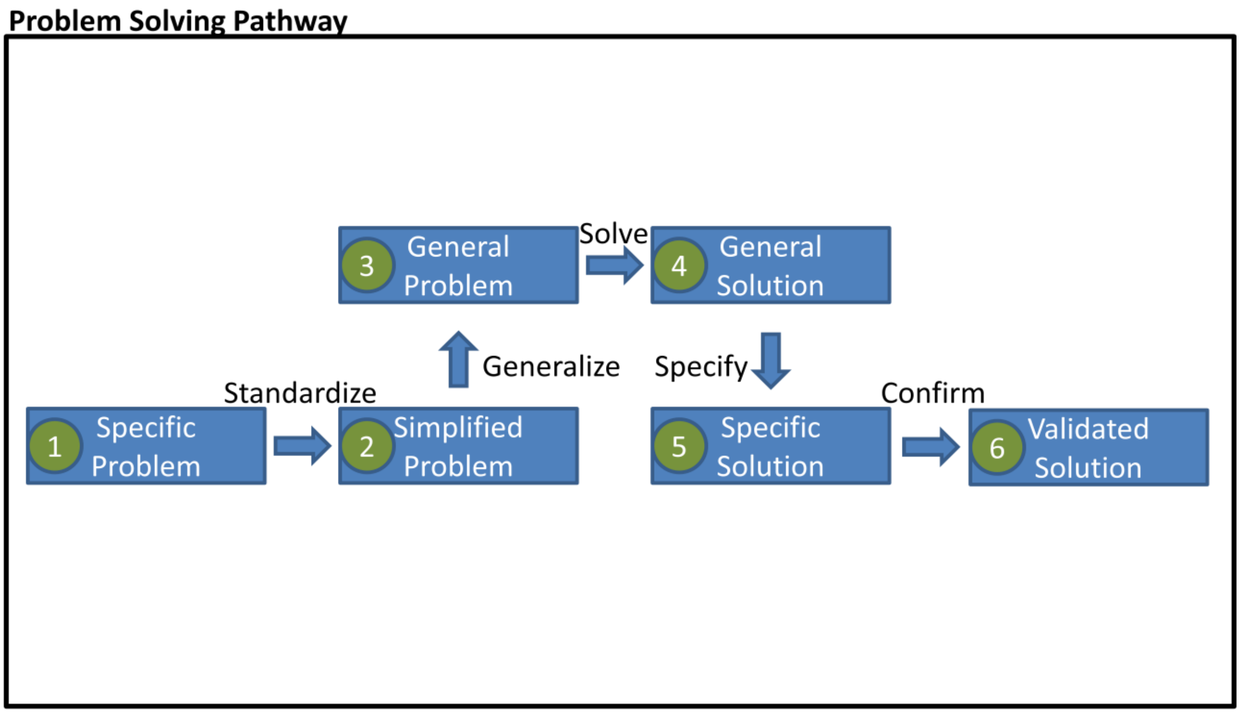


Figure 4

(specific problem to simplified problem - Figure 4). Next, we would determine that we need a way to keep the barn door open in the wind (simplified problem to general problem - Figure 4). Then we would envision ways to keep the barn door open in the wind such as pushing against it or holding it back (general problem to general solution - Figure 4). And finally, we would generate specific solution concepts in achieving the General Solution such as using a latch or propping the door open with a board (general solution to specific solution - Figure 4). However, as mentioned, for a fairly easy problems such as the barn door blowing shut issue, your brain takes you through these steps so rapidly that you do not even know they are occurring. However, when the problem is more complex, and we cannot instinctively move through the solution generation process, we attempt to jump directly from step one (specific problem) to step five (specific solution) of the Problem Solving Pathway (Figure 4) creating unfocused or ineffective solutions (i.e., putting cotton in the livestock's ears during wind storms). Let us reexamine the Problem-Solving Pathway by way of a more complex, yet still somewhat simple, problem. Let us assume that you need to determine how much carpet to buy for your home. Referring to Figure 5, if you attempt to jump from step one (specific problem - "How much carpet to buy?") to step 5 (specific solution - "uhmm.... 1000 sq. feet?), you will most likely be wrong and either buy too much or too little carpeting. If, however, we use all of the steps (Figure 5) it is quite easy to come up with an exact answer even though there is no way to arrive at that result without the intermediary steps.

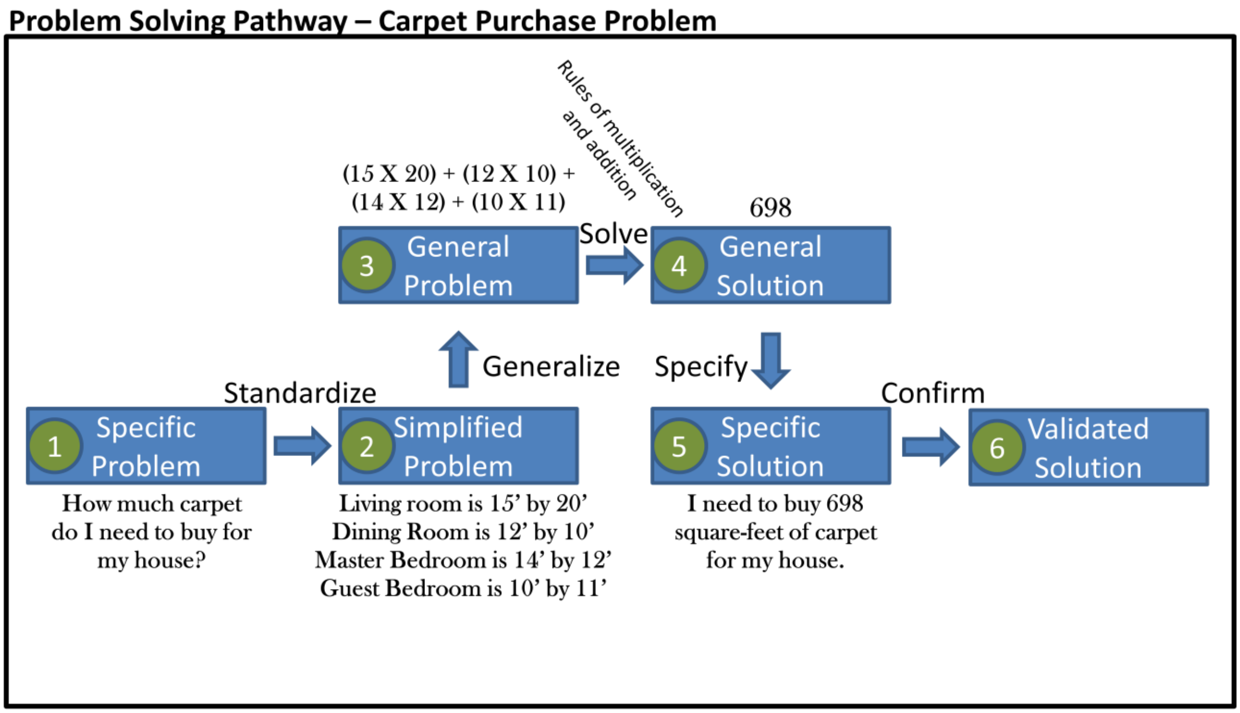


Figure 5

What does the Problem-Solving Pathway have to do with innovation? Clearly "I need to buy 698 square-feet of carpet for my house" is not an innovative solution. One reason why it is not an innovative solution is that no contradictory requirements were resolved in obtaining the answer. So once again, what does the Problem-Solving Pathway have to do with Innovation? It is the process by which innovative solutions can be created. However, as discussed previously, in order to create innovative solutions, there are additional requirements of modeling (Step 3 of Figure 4) and solving (see Steps 4 and 5 of Figure 4) contradictory system requirements within the Problem-Solving Pathway. Further, we will use additional problem-solving methodologies at other steps of the Problem-Solving Pathway thus creating combinations of methods for creating innovative solutions. The next several sections will analyze various problem solving and innovation methodologies to understand what their contributions to an overall innovation process can be and where they will fit into the Problem-Solving Pathway. Following the separate methodologies discussions, I will then return to the options of combining those methods into an orchestrated process.

**Overview of Problem-Solving Methodologies**

During the course of exploring and executing various problem-solving methodologies over the past couple of decades I have come to define two distinct categories of methods: *administrative processes and technical processes*. An *administrative process* specifies what tasks need to be done and the order in which they should be accomplished but does not give any, or at least very little, insight as to how those tasks should be realized. An example of an administrative process might be a chore list left for your children. You could instruct them to straighten their rooms, dust the furniture, vacuum the carpet, and then take out the trash. The tasks, and their order, are specified but there is no technical detail as how to execute any of the tasks.  In comparison a *technical process* would specify not only what needs to be done, and in what order, but would also provide details of how to specifically execute the various tasks (Figure 6).  Therefore, problem solving methodologies categorized as administrative will often benefit from having technical methodologies inserted into their processes.  The combining of administrative and technical methodologies can result in not only a comprehensive and well-ordered set of "what to do" instructions but also simultaneously provides the problem solver with detailed "how to" directions.  Further, some Technical methodologies are focused on individual steps of the Problem-Solving Pathway (Figure 4).  Combining multiple technical methodologies into the proper series can also result in a complete and detailed problem-solving roadmap.  Additionally, rounding out a focused technical methodology by overlaying a decidedly broader but less detailed administrative process can also support the problem solver's goals.   Looking in more detail there are generally five steps in problem solving (Figure 4).  The first activity is to standardize the problem.  The second activity is to generalize the problem.  The third activity is to solve the problem.  The fourth activity is to specify the solution for the situation at hand.  And finally, the fifth activity is to confirm that the applied solution is indeed valid.  I am not aware of any single process (administrative or technical) that address each of the five steps thoroughly.  Many problem-solving methodologies have good tools and processes for executing the first activity, standardization.  Few methods have tools for executing the second and third activities, generalization and problem solving.  Most problem solvers use free association or brainstorming to execute the fourth activity, specification.  And finally, there are only a handful of methods that support the requirement of the fifth activity, solution evaluation.  The following sections will examine several popular problem solving methodologies (in no particular order) in so far as: whether they are more administrative or technical in nature, which steps of the Problem Solving Pathway ( Figure 4) they suffice, and what their relative strengths and weaknesses are.

- **Administrative Direction**
  - Schedule Event
  - Prepare Area for Cleaning
  - Gather Equipment
  - Vacuum Carpet
  - Store Equipment
- **Technical Direction**
  - Remove vacuum from closet
  - Unwrap electrical cord from storage hardware
  - Plug electrical cord into wall outlet
  - Insure vacuum head is set for carpet
  - Toggle power switch to on position
  - Move vacuum back and forth across carpet in a crossing pattern until all debris is removed from floor
  - Push release button on dust bin
  - Carry bin to trash can
  - Open dust bin
  - Shake dust bin over trash can until all loose material is cleared
  - Close dust bin
  - Place dust bin back onto vacuum
  - Unplug electrical cord from wall outlet
  - Wrap cord around storage hardware on vacuum
  - Put vacuum back into closet

Figure 6

**Plan-Do-Study-Act (PDSA)**

Overview - The PDSA cycle is a process for testing a change. Therefore, it is a methodology intended to ensure that changes made to a system have a desired effect. The process is to develop a test plan for the change (plan), execute the test (Do), learn from the results (Study), and decide on modifications to the test (Act).

"The purpose of a PDSA quality improvement effort is to establish a functional or causal relationship between changes in processes (specifically behaviors and capabilities) and outcomes. The PDSA cycle starts with determining the nature and scope of the problem (quadrant 1 of Figure 7), what changes can and should be made, a plan for a specific change, who should be involved, what should be measured to understand the impact of change, and where the strategy will be targeted. Change is then implemented, and data and information are collected (quadrant 2 of Figure 7). Results from the implementation study are assessed and interpreted by reviewing several key measurements (established in the Plan phase of the cycle) that indicate success or failure (quadrant 3 of Figure 7). Lastly, action is taken on the results by implementing the change or beginning the process again (quadrant 4 of Figure 7)."[2] PDSA process are often described as cyclical because they are intended to be repeated until the desired results are achieved. The process assumes that solution concepts will naturally reveal themselves after the initial problem analysis and planning are complete.

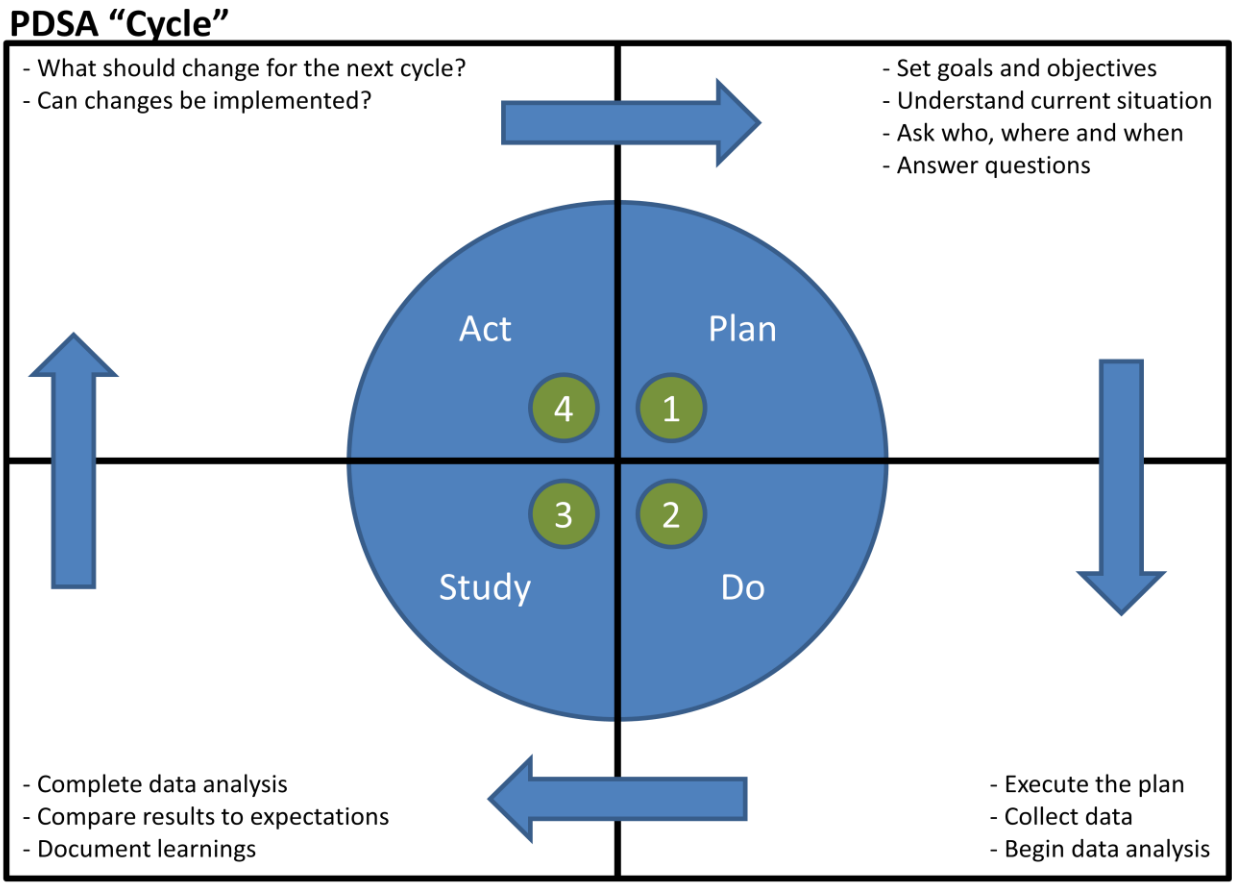


Figure 7

Summary - PDSA is generally an administrative process. The strength of the PDSA process is the guidance it provides to the planning in understanding how changes made to a system effect that system and the guided response to the measurement of the change effect. Most of the PDSA contributions fall into the "standardization" of the problems statement (moving from step 1 and step 2 of the Problem Solving Pathway) and the testing or validation of the specific solutions that would occur between step five (specific solution) and step 6 (validated solution) of the Problem Solving Pathway (Figure 4). The weaknesses of the PDSA process is that it has no tools in support of the development of solutions (changes), innovative or otherwise.

**Six Sigma**

Overview - Six Sigma is a process designed for the reduction of variation in processes. Therefore, it is a methodology intended to support the reduction of errors (misprocessing) in technical and business processes. Six Sigma is one of the most utilized, and therefore most developed, methodologies used in problem solving.

"Six Sigma seeks to improve the quality of process outputs by identifying and removing the causes of defects (errors) and minimizing variability. In Six Sigma, a defect is defined as any process output that does not meet customer specifications, or that could lead to creating an output that does not meet customer specifications."[3] The methodology originated as a set of practices designed to improve manufacturing processes, but its application was subsequently extended to other types of business processes as well. [4] "Six Sigma uses a set of quality management methods, including statistical methods, and creates a special infrastructure of people within the organization ("Black Belts", "Green Belts", etc.) who are experts in these methods. Each Six Sigma project carried out within an organization follows a defined sequence of steps and has quantified financial targets (cost reduction and/or profit increase)." [3] "Six Sigma projects follow two methodologies inspired by the Plan-Do-Study-Act process. These two methodologies are similar, composed of five steps each, and carry the acronyms of DMAIC and DMADV. DMAIC is used for projects aimed at improving an existing process. DMADV is used for projects aimed at creating new product or process designs." [5]

"The DMAIC project methodology is as follows:

- ***D****efine* the problem, the voice of the customer, and the project goals, specifically.
- ***M****easure* key aspects of the current process and collect relevant data.
- ***A****nalyze* the data to investigate and verify cause-and-effect relationships. Determine what the relationships are and attempt to ensure that all factors have been considered. Seek out root cause of the defect under investigation.
- ***I****mprove* or optimize the current process based upon data analysis using techniques such as design of experiments, poka yoke or mistake proofing, and standard work to create a new future state process. Set up pilot runs to establish process capability.
- ***C****ontrol* the future state process to ensure that any deviations from target are corrected before they result in defects. Implement control systems such as statistical process control, production boards, visual workplaces, and continuously monitor the process." [5]

**"**The DMADV project methodology, also known as DFSS ("Design For Six Sigma"), is a follows:

- ***D****efine* design goals that are consistent with customer demands and the enterprise strategy.
- ***M****easure* and identify CTQs (characteristics that are **C**ritical **T**o **Q**uality), product capabilities, production process capability, and risks.
- ***A****nalyze* to develop and design alternatives, create a high-level design and evaluate design capability to select the best design.
- ***D****esign* details optimize the design, and plan for design verification. This phase may require simulations.
- ***V****erify* the design, set up pilot runs, implement the production process and hand it over to the process owner(s)." [5]

Within the individual phases of a DMAIC or DMADV project, Six Sigma utilizes many established quality-management tools that are also used outside Six Sigma. The following table (Figure 8) shows an overview of the main methods used.[6]

**Methods used in Support of Six Sigma Process**

- •5 Whys
- •Analysis of Variance
- •ANOVA Gauge R&R
- •Axiomatic Design
- •Business Process Mapping
- •Cause and Effect Diagram
- •Check Sheet
- •Chi-Squared Test
- •Control Chart
- •Correlation
- •Cost-Benefit Analysis
- •CTQ Tree
- •Design of Experiments
- •Failure Mode Effect Analysis
- •General Linear Model
- •Histograms

Figure 8

What Figure 8 reveals is the significant extent to which other methodologies have been integrated within the Six Sigma process, thus creating combinations of methods. More specific examples of the order in which to use method combinations are presented later in this paper including the combination of Six Sigma with supporting tools.

Summary - While the general steps used within the DMAIC and DMADV methodologies are at first glance mostly administrative in nature the high level of integration with other tool sets pushes the Six Sigma process strongly towards the technical process end of the scale. Further, in relation to the Six Sigma process steps that are dependent upon a high level of integration of the science of statistics, Six Sigma can definitely be considered a technical process, at least within those operations. The strengths of the Six Sigma process lie in its ability to capture analysis requirements for success, the quantification of system performance levels from before and after changes have been implemented, and the focus on follow-up and continuous monitoring. The first three steps of both DMAIC and DMADV fall into the "Standardization" of the problems statement (moving from step 1 and step 2 of the Problem-Solving Pathway - Figure 4). The fourth steps of DMAIC (Improve) and DMADV (Design) align with the "Specify" activity for the specific solution step but unfortunately gives almost no guidance as how to accomplish those tasks. The last step of both of the DMAIC and DMADV processes correlate with the confirm (follow-up/validate) activity supporting step six of the Problem-Solving Pathway (Figure 4). The primary weakness of Six Sigma is that the fourth step of both DMAIC (Improve) and DMADV (Design) are poorly, if at all, supported by any technical processes within the mainstream usage of Six Sigma. In other words, the problem solver is instructed to improve and design at this step but left pretty much up to their own devises in how exactly to do so. Further, A *Fortune* article stated that "of 58 large companies that have announced Six Sigma programs, 91 percent have trailed the S&P 500 since". [7] The summary of the article is that Six Sigma is effective at what it is intended to do, but that it is "narrowly designed to fix an existing process" and does not help in "coming up with new products or disruptive technologies." Advocates of Six Sigma have argued that many of these claims are in error or ill-informed.[8][9]

**Lean (a.k.a. Toyota Production System)**

Overview - Lean is a process for finding and eliminating waste within systems. Initially developed and utilized within manufacturing systems it now enjoys a broader application base including service, health care, and business process in general. Lean is also a heavily utilized problem-solving tool within industry but having the tighter focus of waste elimination than Six Sigma's broader focus of variation reduction results in a smaller but more specifically associated set of tools.

"Lean manufacturing, lean enterprise, or lean production, often simply, "Lean," is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for." [10] "Essentially, lean is centered on *preserving value with less work*. Lean manufacturing is a management philosophy derived mostly from the Toyota Production System (TPS) ... and identified as "Lean" only in the 1990s." [11][12] TPS is renowned for its focus on reduction of the original Toyota *seven wastes* for the purpose of improving overall customer value. In its most common application, Lean is the set of "tools" that supports the detection and constant elimination of waste.

The seven wastes defined by Lean, having the mnemonic TIM WOOD, are:

- **Transport** (the unnecessary movement of material within the manufacturing process)
- **Inventory** (all material, parts, work in process and finished goods waiting for processing or movement)
- **Motion** (people, equipment or machinery moving beyond that distance required for the manufacturing process)
- **Waiting** (any production system component or output waiting for the next operational step)
- **Over Production** (production in excess of demand)
- **Over Processing** (material processing beyond that required for the final product)
- **Defects** (any production result requiring inspection or repair)

Waste elimination naturally results in a reduction in production time and cost while with a simultaneously improvement in production quality. Value Steam Mapping (VSM) is one problem identification tool used within Lean to help identify waste. Further, VSM, workspace organization, pull systems and error-proofing are tools used to generate solutions, or responses, to the identified wastes.

"There is a second approach to Lean Manufacturing, which is promoted by Toyota, in which the focus is upon improving the "flow" or smoothness of work, thereby steadily eliminating unevenness through the system and not upon 'waste reduction' per se. This is a fundamentally different approach from most improvement methodologies, which may partially account for its lack of popularity. While waste elimination and production smoothing appear to have slightly different pursuits both methods ultimately drive to the same result. The implementation of smooth flow exposes quality problems that already existed, and thus waste reduction naturally happens as a consequence. The advantage claimed for this approach is that it naturally takes a system-wide perspective, whereas a waste focus sometimes wrongly assumes this perspective." [13]

"The application of Lean to industries outside of manufacturing has resulted in different definitions of the seven wastes. One redefinition of these wastes for service operations by Bicheno and Holweg (2009) is as follows:

- 1. ***Delay*** on the part of customers waiting for service, for delivery, in queues, for response, or not arriving as promised.
- 2. ***Duplication***. Having to re-enter data, repeat details on forms, copy information across, answer queries from several sources within the same organization.
- 3. ***Unnecessary Movement***. Queuing several times, lack of one-stop, poor ergonomics in the service encounter.
- 4. ***Unclear communication***, and the wastes of seeking clarification, confusion over product or service use, wasting time finding a location that may result in misuse or duplication.
- 5. ***Incorrect inventory***. Being out-of-stock, unable to get exactly what was required, substitute products or services.
- 6. ***An opportunity lost to retain or win customers***, a failure to establish rapport, ignoring customers, unfriendliness, and rudeness.
- 7. ***Errors in the service transaction***, product defects in the product-service bundle, lost or damaged goods." [14]

Summary - Lean's tight focus on waste elimination along with fairly standardized solution generation tools, pushes it somewhat towards the Technical Process end of the scale. The categorization of the Seven Wastes along with the standard solutions to responding to them does provide a somewhat specific "how to" directions to the problem solver. The strengths of Lean lie in its focus on waste reduction, opposed to a general focus on problem solving, and its somewhat well-defined operating definitions and guidance. The waste identification steps in the Lean process generally move us from step two to step three (Generalize) of the Problem Solving Pathway (Figure 4) while the solution tools (i.e., work space organization, error proofing, etc.) move the user from step 3 to step 4 (General Solution) of the Problem Solving Pathway. The weaknesses of the waste elimination portion of Lean include a non-system level approach and the inability to thoroughly and technically direct the problem solver in waste elimination. Non-system level analyses can create micro changes that appear useful at the point of application but that ultimately harm the overall output of the entire system. The lack of technical direction in the "how to" of waste elimination can create situations when it is not obvious how to reduce waste and eliminate errors in the process due to Lean's lack of depth of analysis of the process itself.

**Root Cause Analysis**

Overview - Problems solvers often mistakenly focus on effects or symptoms of problems when looking for solutions because those effects and symptoms are what are most visible when analyzing an issue. Root Cause Analysis (RCA) is a graphical and textual technique used to understand complex systems and the dependent and independent fundamental contributors, or root causes, causing the issue, or problem, under analysis. It allows the problem solver to better understand and visualize the complex relationships between causes and helps point the way to the shortest solution path and the most effective solutions options. While "Root Cause Analysis (is) used extensively in engineering [15]" it is also effectively applied to other types of systems including computing, organizational, social, and political to name a few.

The RCA methodology fundamentally works as follows (refer to Figure 9):

1.) Identify an initial situation or problem (i.e., "Fluid Pumps are Expensive to Run") and document that situation

2.) Ask the question "why?" and capture that information below the initial situation

3.) Keep in mind that the answers to "why?" can be both theoretical and factual - including theoretical situations helps to uncover hidden issues that may not have been previously realized

4.) Discreet causes are captured separately

5.) Capture "And" relationships between interdependent cause chains (since both chains must be true for the resulting effect to occur only one of the chains must be addressed)

6.) Continue each line of cause analysis until a fundamental cause (law of nature, program boundary condition, organizational requirement, etc.) is reached

7.) Once all of the independent root causes are addressed then the initial problem will be resolved

## RCA Analysis of Pump Operations Cost

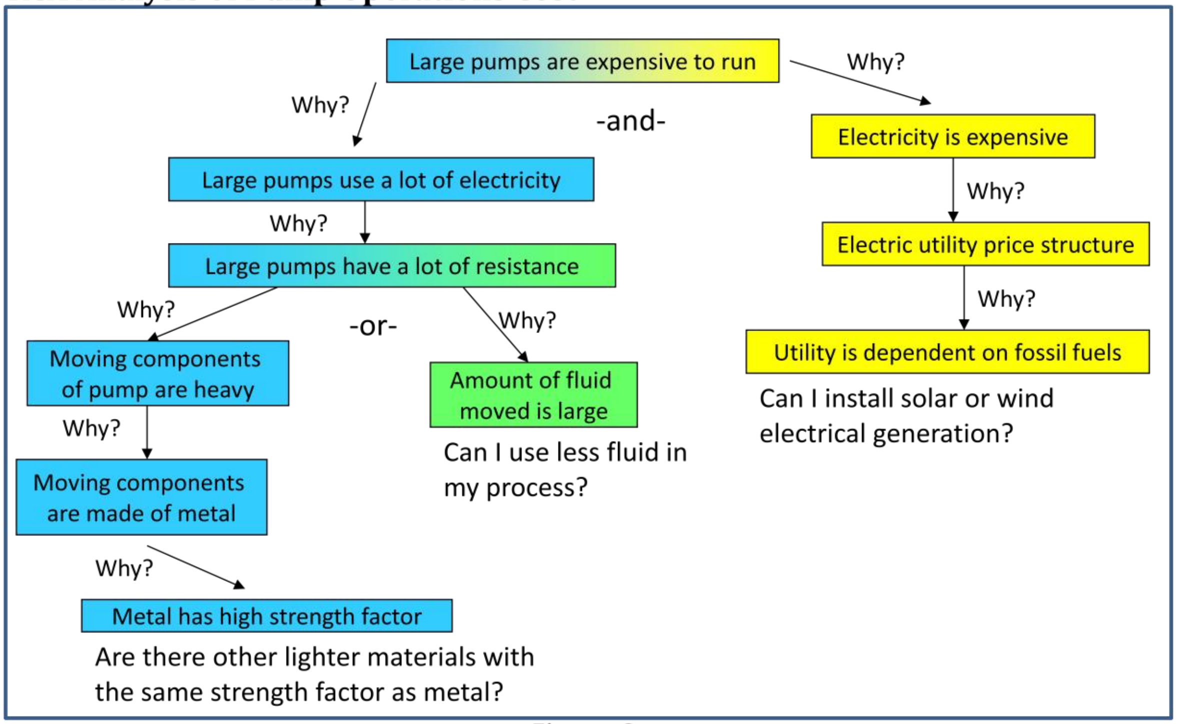


Figure 9

The final step of a traditional RCA is developing recommendations for system and process improvement(s), based on the findings of the investigation. [16] The importance of this step is supported by a review of the literature on root-cause analysis, where the authors conclude that there is little evidence that RCA can improve .... (a condition) by itself. [17] The root causes are analyzed in light of why that root cause exists in order to help create a simplified problem. For example, one root cause as to why the internal combustion engine is damaging to the environment is because the system utilizes carbon-based fuels. There are several reasons why internal combustion engines utilizes carbon-based fuels which make their elimination difficult. One of the reasons why it is currently the fuel of choice is that carbon-based fuels represent a high energy density source. Once the reasons for the existence of a root cause is understood the information needed to understand the associated limiting contradiction is available. See the section titled Contradiction Analysis for more on contradiction modeling.

Summary - The RCA technique is a technical process in that it provides specific direction as how to execute the method. One of the strengths of RCA is that it combines textual information (reasoning) with a graphical format (RCA mapping) to create a visual record of what situations are contributing to an issue. Further this visual record also reveals the relationships between the various RCA paths (chains) so that convergent solutions can be applied often creating more efficient solution paths. The RCA analysis process moves us from step one (Specific Problem) to step two (Simplified Problem) of the Problem-Solving Pathway (see Figure two). The weakness of the process is, like most other problem solving methods, it has no solution generation tools to support elimination of the initial issue or the identified root causes. However, the resolution provided by RCA in capturing the various causes of an issue reveals exactly where solution development should be focused.

**Functional Analysis**

Overview - Functional Analysis is a graphical and primarily qualitative methodology used to focus the problem solver on the functional relationships (good or bad) between system components. A function model or *functional model* .... is a structured representation of the functions (activities, actions, processes, operations) within the modeled system or subject area. [18] The process is effective because concentrating on system function is not only the correct concern (all systems exist solely to provide some function) but once functionality is the target then the mental inertia of how to address issues within the system is greatly reduced as there is no longer a focus on the system components. Functional Analysis is particularly strong is supporting other analysis methodologies as it is an excellent problem modeling tool that can be used for any and all system problems.

One of the first well defined function models, was the Functional Flow Block Diagram (FFBD) developed by the defense-related TRW Incorporated in the 1950s. [19] In the 1960s it was exploited by the NASA to visualize the time sequence of events in a space systems and flight missions. [20] It is further widely used in classical systems engineering to show the order of execution of system functions. [21]

A functional model, which concentrates on component functional interrelationships and not the order of operation, is constructed by documenting a set of system components connected by titled arrows showing interface relationships. The purpose of titling the arrows is for the purpose of identifying the functions occurring between the system components. Components are the physical items within the system that combine to create the system (i.e., wheel, magnetic field, wire, bracket, accountant, sales manager, etc.) and the environment it operates within and interfaces with.

Creation of a Functional Model (Figure 10) is as follows:

1.) List the components that make up the system under analysis and the components they operate within (i.e., gravity)

2.) Create a graphic with all of the system components document within boxes

3.) Use different box styles (Figure 11) to delineate system components, environment components and the focus of the system (the system focus is the component the system was designed to effect - in Figure 10 the focus of the system is the auditory nerve)

> For example a refrigerator is a system comprised of several components (insulated box, compressor, heating coil, refrigerant, etc.) that operates on, or effects, the system's focus (i.e., food) and operates within various environmental components (i.e., ambient air).

4.) Connect the interfacing components with arrows showing the functional relationships

5.) Document the function title by each arrow

6.) Note which functions help the system (good) or hurt the system (harmful) and for the good ones, document if the function is insufficient, sufficient, or excessive. Annotate the functional model by way of changing the arrow line formats according to the Function Type Legend (Figure 11).

**Functional Model of Cochlear Implant**

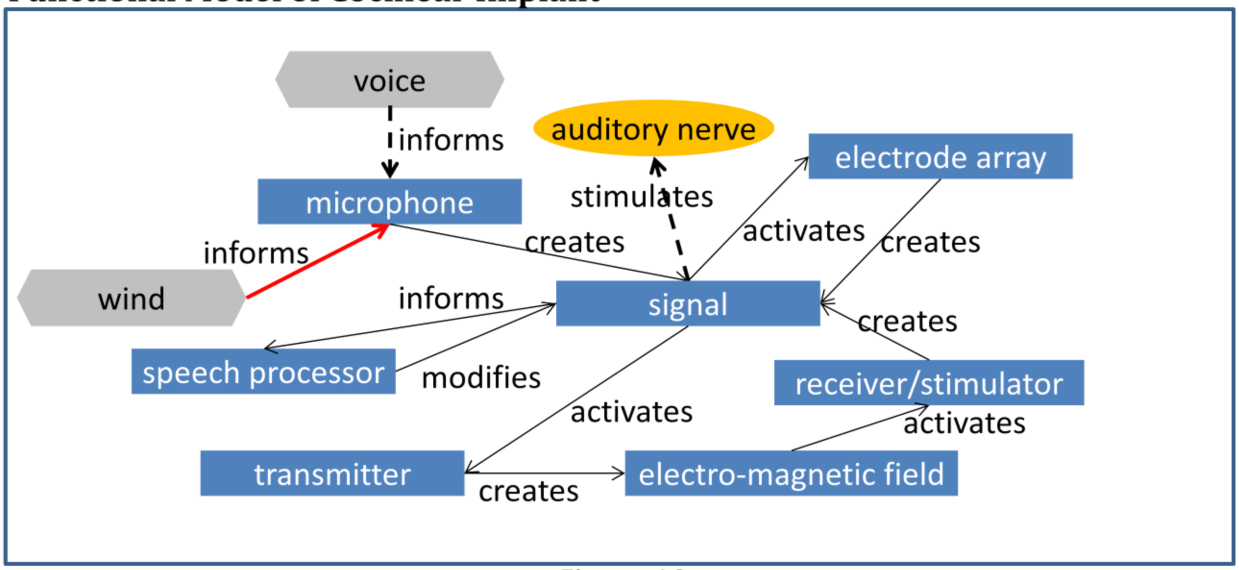


Figure 10

**Legend**

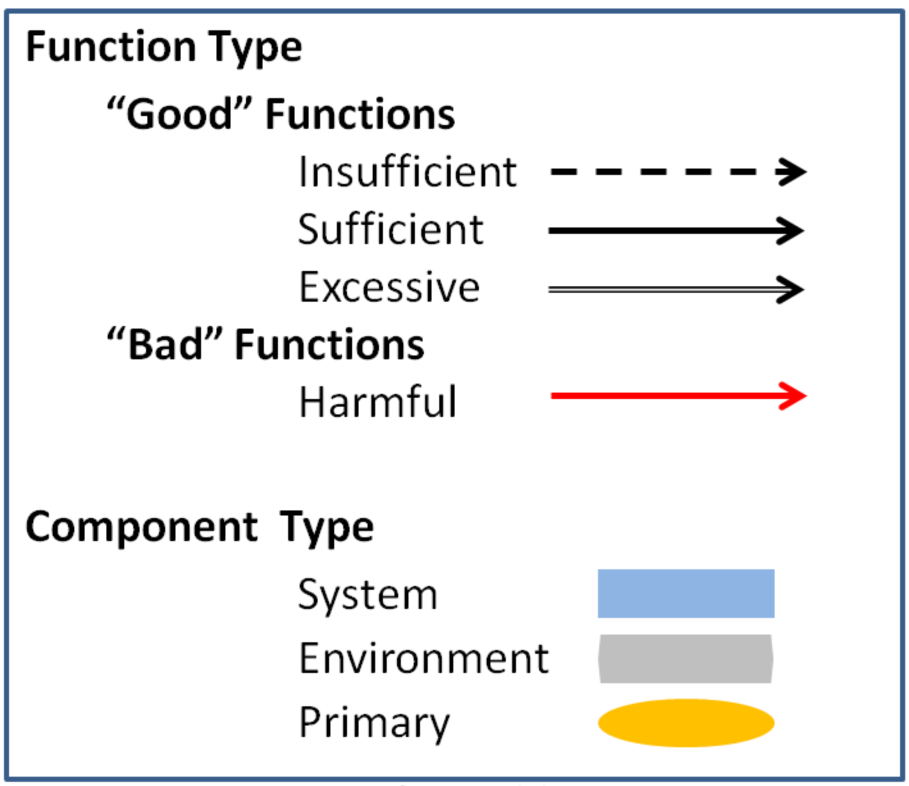


Figure 11

The functional model is used to show the type (good or bad) of the function along with its level (insufficient, sufficient, excessive) so that the problem solver can identify limiting situations within the system. Once the limiting situations are identified then contradiction modeling can be completed and innovative solutions developed.

Summary - The *Functional Modeling* (*Functional Analysis*) technique is a technical process in that it provides specific direction as how to execute the method. One of the strengths of functional modeling is that it combines textual information (components and functions) with a graphical format (functional mapping) to create a visual record of how a system operates and what its strengths and weaknesses are. The Functional Analysis process moves the problem solver from step one (specific problem) to step two (simplified problem) of the Problem-Solving Pathway (Figure 4). The weaknesses of the process is that, like most other problem solving methods, it has no solution generation tools to support elimination of the initial issue. However, the resolution provided by functional modeling in capturing the interrelationships between system components provides tremendous insight as to where system improvements can be made and therefore where solution development should be focused.

**Systems Engineering**

Overview **-** The term *systems engineering* can be traced back to Bell Telephone Laboratories in the 1940s. [22] The need to identify and manipulate the properties of a system as a whole, which in complex engineering projects may greatly differ from the sum of the parts' properties, motivated the Department of Defense [23], NASA, and other industries to apply the discipline. [24] While the term systems engineering implies an application to the world of machines and tools the analysis can be applied to any system that is made up of multiple components. Banks, hospitals, server farms, spacecraft and forests are all systems that can be analyzed through the lens of systems engineering.

There are a variety of methods by which Systems Engineering or Systems Analysis can be applied in problem solving. The basic goal is to ensure that the problems solver understands how a change to, or problem with, a system component will affect the rest of the system. For example, if a company requires the accounting department to work 12 hour days during its annual internal audit it is important that the company understand how those 12 hour shifts for the accounting employees will impact the rest of the organization. Can the accounting department effectively audit the organization if every other department is only there eight hours a day? Does security need to be expanded during the audit because more personnel will be on site longer each day? How will morale for the accounting employees be affected by the longer hours? Further, if a fuel pump is to be heated to improve cold weather operations how will the addition of that heat affect the system as a whole? Will the heat cause fuel volatility issues within the system? Are there any sensitive electronics that may be adversely affected by the heat? Can the heat create additional desirable effects within the system?

The multiple types of system engineering analyses make it impossible to describe each of the usages however, I will describe what I think to be the most effective usage, *System Function Analysis*. A *systems functional analysis* (see above) can be executed between as few as two components (i.e., battery and micro processor) or between all system components (i.e., all components within a cell phone). If the analysis is expansive and all inclusive, then it can be considered a system engineering or system analysis. Referring to the section on Functional Analysis will provide directions as to how to apply Systems Engineering to a problem analysis.

Summary - Systems Engineering (System Analysis) is a technique to ensure that full system effects, impacts, benefits and responses are understood when looking at changes or problems within a system. The various manifestations of the Systems Engineering methodology are more Technical Processes than they are Administrative Processes as they are fairly specific as to how to create and utilize the various Systems Engineering models. However, the use of the Systems Engineering Process is meant to guide the problem solver in so far as understanding that full system analysis is necessary in creating truly effective solutions. Therefore, I categorize Systems Engineering as more Administrative in nature than Technical. One of the strengths of Systems Analysis (specifically System Functional Analysis) is that it combines textual information (components and functions) with a graphical format (functional mapping) to create a visual record of how a system operates and what the system's useful and harmful functions are. The Systems Analysis process moves the problem solver from step one (specific problem) to step two (simplified problem) of the Problem-Solving Pathway (Figure 4). The weaknesses of the modeling method is that it has no solution generation tools to support elimination of the identified issues. However, the resolution provided by Systems Analysis in capturing the interrelationships between system components provides tremendous insight into where system improvements can be made and therefore where solution development should be focused.

**Contradiction Analysis**

Overview - *Contradiction analysis* is the process of identifying and modeling contradictory requirements within a system which, if unresolved, will limit the performance of the system in some manner. If a *limiting system contradiction* is resolved with the application of a solution, then that solution can be considered an innovative solution. Contradiction analysis can be appended to most any problem identification process such as Six Sigma, Lean, Functional Analysis and Root Cause Analysis. Contradiction analysis and resolution is part of the science of innovation referred to as the Theory of Inventive Problem Solving also know by the acronym TRIZ.

Within the discipline of TRIZ there are two fundamental types of contradictions that can be modeled. These two contradiction forms are referred to as Engineering and Physical Contradictions. Engineering contradictions exist when an attempt to improve one parameter of a system leads to the worsening (impairment) of another system parameter. For example, the strengthening of an automobile's passenger compartment by way of the addition of steel also renders the automobile heavier. The improving parameter of the automobile (strength) is unwittingly countered by a worsening of another of the automobiles parameters (weight). In this example the goal of contradiction analysis would be to resolve the contradiction by increasing the automobile's strength without adding to the automobile's weight. Further, if a surgical procedure is changed in such a way as to make it safer for the patient but the changes also renders the procedure more complex then the surgery parameter of safety is improved while the surgery parameter of complexity is worsened. Physical Contradictions exist when a single system parameter must exist in two differing states (see Figure 1 for three examples of physical contradictory requirements of a system).

Summery - Contradiction analysis is the process of identifying and resolving contradictory requirements within a system or process. The method is a Technical Process as the requirements for creating and solving contradiction models are very specific. Inclusion of contradiction analysis and resolution into a problem-solving process is required if the goal is to purposely drive towards innovative solutions. The strength of contradiction analysis is that it allows the problem solver to view a problem in its most elementary state in order to fully understand what within the system is making contradictory demands of the system. Contradiction analysis moves the problem solver from step two (simplified problem) to step 4 (general solution) of the Problem-Solving Pathway (Figure 4). The weaknesses of the modeling method is that if the problem solver does not already have a good understanding of the system components, or root causes, that are responsible for the contradictory demands on the system then a methods must first be employed to identify the contradictory system limitations. In other words, it is not a standalone methodology if the contradictions are not already identified.

**Brainstorming**

Overview - Brainstorming is an individual or group effort where solutions to a specific problem are spontaneously generated and captured. The goal is to generate as many solutions concepts as possible without being hindered by any restrictions or boundary conditions. Therefore, any idea is valid as initially generated and should be included in the brainstorming session's solution listing. However, I feel that the process is marginally effective at generating effective and workable solutions especially if the brainstorming is not focused on a well-defined model of the root problem. According to an on-line article from The New Yorker magazine, Keith Sawyer, a psychologist at Washington University, has summarized the science of brainstorming: “Decades of research have consistently shown that brainstorming groups think of far fewer ideas than the same number of people who work alone and later pool their ideas.”[25]

Because of the limitations and challenges of standard brainstorming I instead suggest the use of a method I have traded marked as *Technically Focused Brainstorming ™*. It should be noted that *Technically Focused Brainstorming* ™ is specifically designed to be used in conjunction with contradiction analysis and therefore is not applicable if contradiction analysis is not utilized within the Problem-Solving Pathway. In the situations where contradiction analysis is not, utilized then the problem solver has no real choice except to use standard brainstorming or other mental inertia breaking techniques.

**Technically Focused Brainstorming ™**

Overview - *Technically Focused Brainstorming* ™ is a term I created to describe the use of standard brainstorming methods bounded by certain acceptable solution concept conditions and guided by the attainment of an ideal solution. More specifically, any solution concept is acceptable as long as that solution concept meets two important criteria. The first criteria is that the solution concept must plausibly resolve the contradiction identified by a previously accomplished contradiction analysis. Secondly, the solution concept must move the system under analysis in the direction of the *Ideal Final Result*. The concept of *Ideal Final Result* is that in order to improve a system or process the output of that system must improve (i.e., volume, quantity, quality, etc.), the cost of the system must be reduced, or both. In other words, the system's or process's value must increase by the utilization of the solution concept being tested.

Summary - The methodology of Technically Focused Brainstorming ™ is a technique that guides the generation of solution concepts by insuring that those solution concepts support the resolution of contradictory requirements of the system under analysis and renders that system to be of higher value than it was before the solution was applied. It is mainly an administrative process as it instructs the problem solver as to what the goals of the process are but generally leaves it up to the problem solver to devise how to accomplish the directives. The strength of Technically Focused Brainstorming ™ is that it bounds the less effective and more simplistic method of Brainstorming by guiding the problem solver to create solution concepts that will resolve system contradictions and improve the value of the system under analysis. The Technically Focused Brainstorming ™ process moves us from step four (General Solution) to step five (Specific Solution) of the Problem-solving Pathway (Figure 4). The weakness of the Technically Focused Brainstorming ™ methodology is that it can only be applied in problem solving efforts where contradiction analysis and resolution has already been completed.

**Methodology Merger**

Now that several methods, including where they fit into the overall innovation process, have been discussed it is possible to better define how they can be tied together to create a seamless and powerful tool set. Each methodology brings with it certain strengths and serves to fulfill specific steps and activities represented on the Problem-Solving Pathway (Figure 4). Therefore, when combined together and properly utilized, these methodologies create a very effective and useful outcome (see Problem Solving Pathway - with Transitional Tool Options, Figure 12). This is one of those situations where the whole is more powerful than the sum of its part's. Studying Figure 12 it can be seen that except for the generalize transitional phase, there are multiple problem-solving methodologies associated with the transitional phases between the various problem-solving steps. There may very well be additional processes that could also be used at the generalize phase, but contradiction analysis is the only one I propose using considering that the goal is to generate innovative solutions, not just solutions. There are many additional processes that could have also been included on other portions of the pathway, but I have limited the inclusion to the most popular and most effective, at least from my experience. At least one methodology must be used for each transitional phase, but it is also perfectly acceptable to use multiple methodologies at each transitional phase. In the section tilted Problem Solving Versus Innovation, I explained that in order for a solution to a system problem to be innovative it must solve a limiting system contradiction. Therefore, if it is an innovative solution being pursued then the transitions between steps two and three and steps three and four must use contradiction analysis as the transitional engine. Figure 13 shows some of the method combination options and the scenarios in which they could be used. For example, if it is desired to use an existing Six Sigma analysis as the basis for an innovation development project then referring to line item number two in Figure 13 the problem solver would use the first three steps of the Six Sigma process to convert the Specific Problem into a Simplified Problem. Next, contradiction analysis would be used to convert the simplified problem into a general problem and then a general solution. Then, Technically Focused Brainstorming ™ would be used

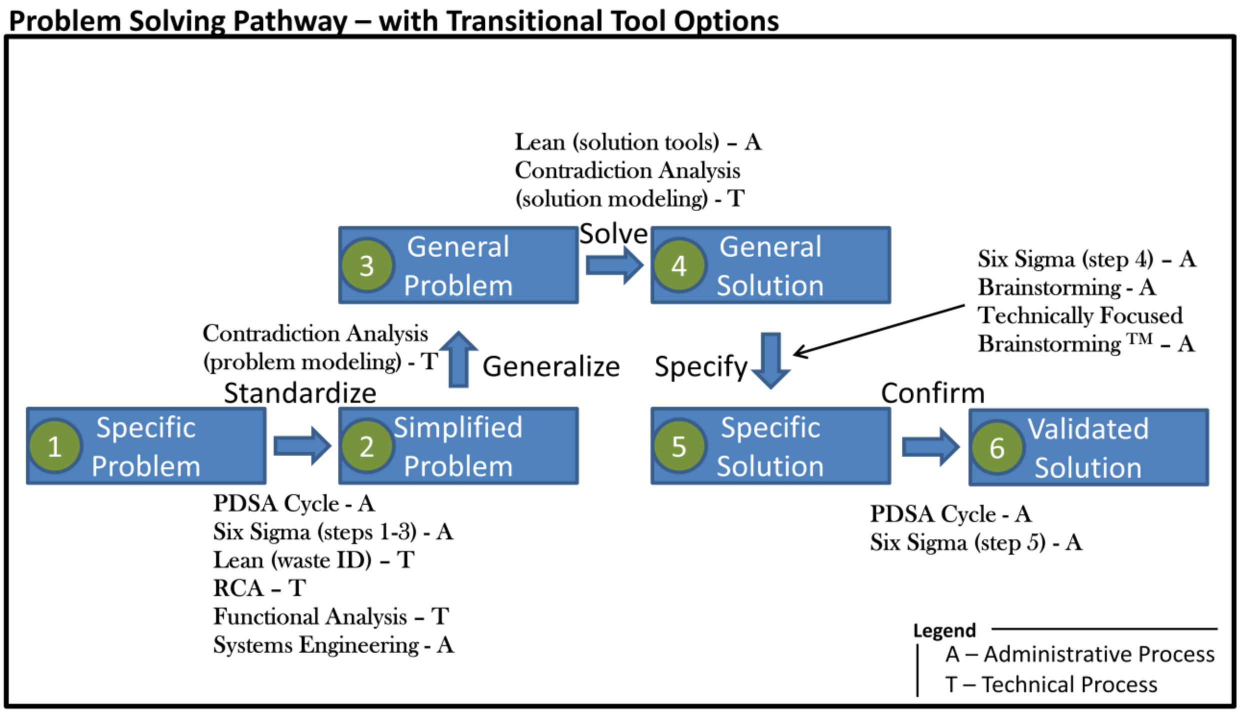


Figure 12

to convert the general solution into a specific solution. And finally, the problem solver would then once again return to the fifth step of the Six Sigma process to validate that the implemented solution concept had the intended effect. A real-world example of the use of this particular combination of methodologies can be seen in the section titled Operating Room Utilization Improvement - Variation Reduction Innovation Study. As another example it is possible to innovate an existing technical system. For this process I would suggest using the methods of System Innovation found online item numbers four and five of Figure 13. First, Root Cause or Functional Analysis (or both) would be used to convert the specific problem into a simplified problem (Figure 12). Next, contradiction analysis would be used to convert the simplified problem into a general problem and then a general solution. Then, Technically Focused Brainstorming ™ would be used to convert the general solution into a specific solution. Since there is no specific solution validation tool set associated with System Innovation (Figure 13) the problem solver could execute the above process within the PDSA Cycle process and use the PDSA Cycle (steps three and four - Figure 7) as the solution validation engine. A real-world example of the use of this particular combination of methodologies can be seen in the section titled Wireless Power System Improvement - System Innovation Case Study.

| Combination Methods Summary Chart | | | | | | |
|---|---|---|---|---|---|---|
| | | Transitional Methodologies for: | | | | |
| LI # | Problem Solving Focus | Standardize | Generalize | Solve | Specify | Confirm |
| 1 | Innovation with Change Control | PDSA | Contradiction Analysis | Contradiction Analysis | Technically Focused Brainstorming ™ | PDSA |
| 2 | Innovation in Variation Reduction | Six Sigma | Contradiction Analysis | Contradiction Analysis | Technically Focused Brainstorming ™ | Six Sigma |
| 3 | Innovation in Waste Reduction | Lean | Contradiction Analysis | Contradiction Analysis | Technically Focused Brainstorming ™ | - |
| 4 | System Innovation | RCA | Contradiction Analysis | Contradiction Analysis | Technically Focused Brainstorming ™ | - |
| 5 | System Innovation | Functional Analysis | Contradiction Analysis | Contradiction Analysis | Technically Focused Brainstorming ™ | - |
| 6 | Variation Reduction | Six Sigma | - | - | Six Sigma | Six Sigma |
| 7 | Waste Reduction | Lean | - | Lean | Brainstorming | |
| 8 | Change Management | PDSA | | | Brainstorming | PDSA |

Figure 13

**Case Studies**

Let us look at some case studies to review how the various combinations of methodologies coordinate to produced accelerated results. It should be noted that since the goal is to create innovative solutions both examples, regardless of what other methodologies are utilized within the process, will employ the use of contradiction analysis at steps three and four of the Problem Solving Pathway (Figures 4 and 5).

**Operating Room Utilization Improvement - Six Sigma Case Study**

I was hired by a hospital chain to help improve the utilization rate of the operating room (OR) suites. As expected, a hospital's OR suites are expensive resources and utilizing them at a high rate is crucial to effectively running hospital business. The hospital's staff of Six Sigma Black Belts had already conducted a statistical analysis of several parameters associated with the use of the ORs and one of those analyses involved understanding at what rate the ORs were being utilized. OR utilization was below 60% in general and below 50% for some of the more specialized OR suites such as the ones constructed and outfitted for brain surgery. Ultimately over 35 contradictions were modeled and solved for this project but for the sake of brevity I will discuss only one of the identified issues. The main operational factor effecting OR utilization was turn over time between operations. This turn over time was even more impacted by utilizing a single OR back to back for two different types of surgery (i.e., heart surgery vs. knee surgery). Therefore, the transition from step one (specific problem) "Low utilization of the ORs" to step 2 (simplified problem) "Poor turn over time" (Figure 14) was completed using the Six Sigma process. Next, the transition from step 2 (simplified problem) to step 3 (general problem) was completed by way of contradiction analysis. While there are usually several ways that any particular problem can be reflected as to its contradictory requirements, I will discuss just one such contradiction. The simplified problem of "poor turn over time" can be analyzed in so far as whether or not the ORs are standardized in their layouts, equipment, and facilities. Highly standardized OR Suites (Situation 1 - Figure 15) with the flexibility to perform any type of operation in any of the ORs would be expensive while also being very flexible. On the other hand, highly specialized, with low standardization, ORs (Situation 2 - Figure 15) which could only host specific types of operations by OR configuration would be

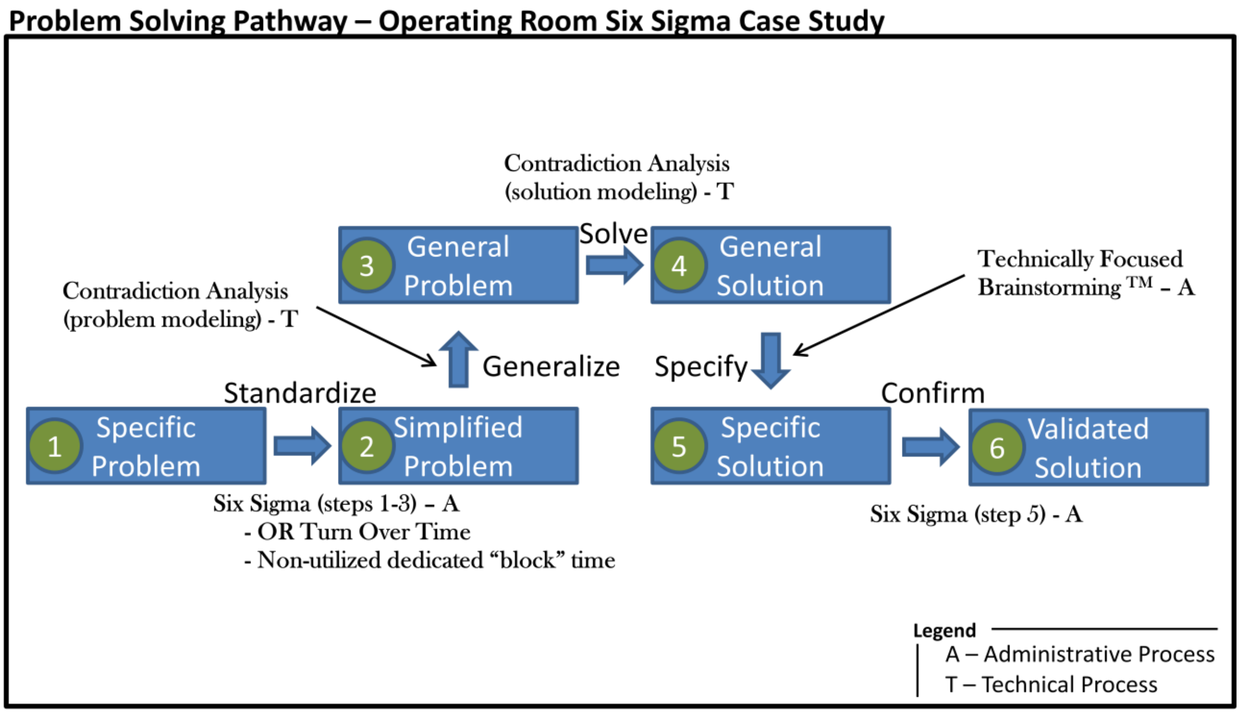


Figure 14

much less expensive and, of course, not very flexible. High standardization would help OR utilization by making turn over time shorter. Once again referring to Figure 14, the transition from step three (general problem) to step 4 (general solution) is represented by the merger of the two desirable results from the problem models (Figure 15) created by some yet to be determined system design (Figure 16). Therefore, the abstract model that solves this contradictory requirement for the ORs to be both highly standardized and highly specialized simultaneously would look like the diagram in Figure 16. The "unknown solution" (represented by the large white circle) would result in less expensive facilities (represented by small green circle) while simultaneously providing a very flexible facility (represented by the large orange circle). The solution should result in the "good" effects represented by the two differing problem models (less expensive facilities and very flexible). Next, utilizing Technically Focused Brainstorming ™ (see Figure 14) to transition the analysis from step four (general solution) to step 5 (specific solution) the team developed specific solutions that transcended the system's contradictory requirements, as reflected in the associated contradiction analysis, and simultaneously increased the system's value. While over 450 solutions were developed for the more than 35 analyzed contradictions only a few will be shared. One of the more interesting solutions I developed, which is now in use at the organization's newest facility, is to completely eliminate the utilization issue of the expensive OR suite by operating directly in the inpatient's hospital room. Clearly this did not completely solve the utilization issue as only a small subset of operations are suitable for executing in a standard hospital room but it did greatly reduce the turn over requirements by removing some of the change over demand and thus raising overall utilization. A second solution developed for the project was to incorporate a visual feedback system to the operational environment. It is understood by efficiency experts that providing real time feedback to teams is necessary in order to drive the team's performance to highly effective levels. The conceptualized visual feedback system takes two primary forms: 1.)

## Conflicting Situations Graphic – OR Utilization

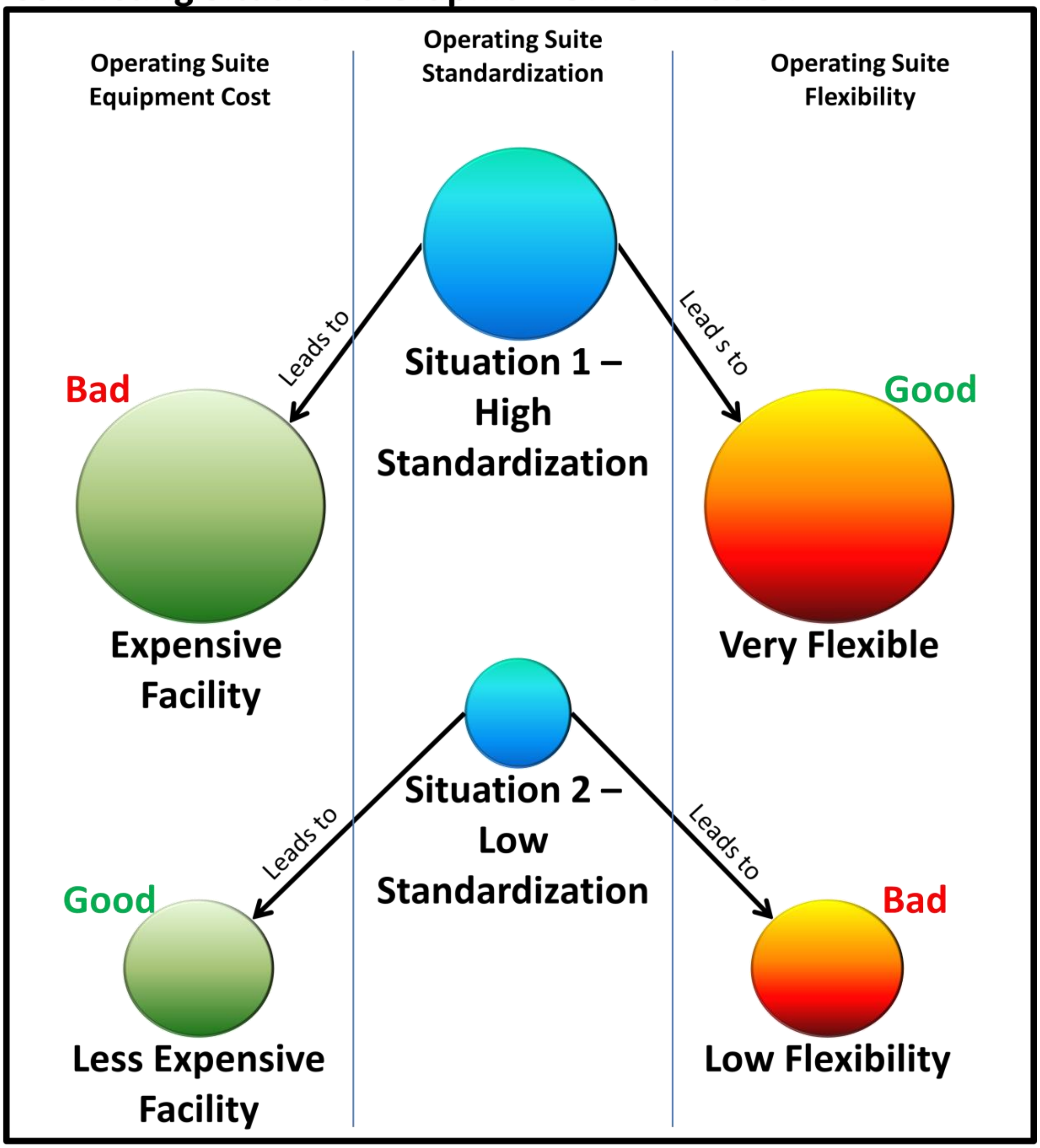


Figure 15

## Conflicting Situations Graphic – OR Utilization

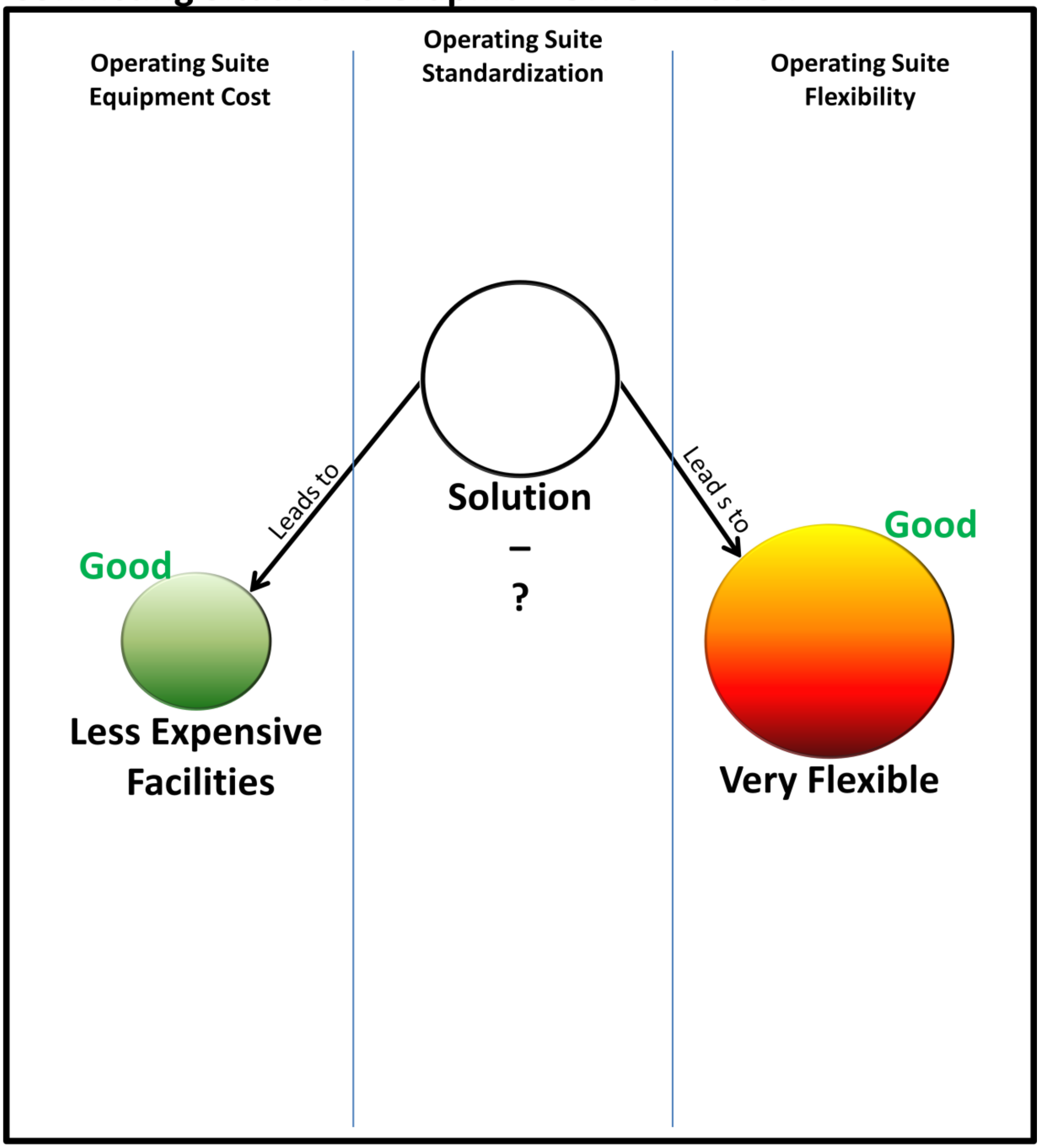


Figure 16

display a large wall timer visible to all personnel, responsible for OR turn around, that shows how long an OR has been out of service since the finish of the previous operation and 2.) radio tag all equipment (including personnel) so that its location can be readily understood and it is easy to known when all necessary components are indeed where they are suppose to be. Following the analysis and solution phase of the project certain choice solutions were implemented and then Six Sigma was once again used to statistically measure the impact to OR utilization. Therefore, Six Sigma was used to transition the team from step five (specific solution) to step 6 (validated solution) of Figure 14.

**Wireless Power System Improvement - System Innovation Case Study.**

While working for the worlds largest semiconductor manufacturing corporation I was asked to support the improvement of new wireless power system for use on mobile computing and phone devices. Wireless power is a technology where power is provided to electrically powered systems without the use of the ubiquitous power cord. It is not hard to imagine the advantage of having battery powered electronic devices that would never need to be physically plugged into an electrical outlet in order for them to be charged. The company had a working system but the range over which it would work effectively was quite short (several inches). The goal of the project was to extend the range, up to several feet, over which the wireless power system would operate. First it was necessary to establish the specific problem in step one of the Problem-Solving Pathway (see Figure 17 - Problem Solving Pathway - Wireless Power System Improvement Case Study). Many times, the specific problem can be established by simply restating the problem as initially presented. Therefore, in this case the specific problem could be formulated as “the effective operating range of the wireless power system is very limited." To innovate solutions in improving the system I used the Functional Analysis System Innovation combination of methodologies found online item 5 of Figure 13. It was first necessary to transition the specific problem (step 1) into a simplified problem (step 2) of Figure 17. According to Figure 13 the standardization process associated with line item number five calls for the use of Functional Analysis. In order to build a functional model some type of information (drawings, description, etc.) can be used to guide the development of the model. I used a schematic of a generic wireless power system as the basis for a functional model of the wireless power system (Figure 18). As can be seen it is necessary to understand how a system physically operates in order to understand how to functionally model that system. System experts are quite useful, and often necessary, in properly creating Functional Models. If the modeling is not correct there is a slim chance of creating any meaningful solutions to the initial problem, innovative or otherwise. In studying the resulting Wireless Power System Functional Model (see Figure 19) it can be seen that there are four insufficient functions listed within the model. How did I know to make the functions of Absorbs and Emits EMF (electro-magnetic field) insufficient within the Functional Model? Quite simply, since the existing system is not capable of transmitting power over long distances then the emission and absorption of the EMF must be insufficient. You will also notice that the production of EMF and Current 3 are also listed as insufficient but these issues will be ignored for this analysis as the first insufficiency can be rectified by simply increasing the power source and the second insufficiency will be rectified when the power transmission is improved. Returning to the power transmission issue it was necessary to understand the reason for the insufficiencies in order to generate properly formulated and solve a Contradiction Model. Therefore, a little background on wireless power system deficiencies was useful. In summary, the primary system design parameters that control how well a wireless power system can transmit power across a significant distance are the shape, size, and orientation of the transmission (Tx) and receiver (Rx) coils (see Tx Coli and Rx Coil in Figures 18 and 19). Large round coils, around 30 centimeters in diameter, with their faces positioned parallel to each other can transmit and receive electro-magnetic

**Problem Solving Pathway – Wireless Power System Improvement Case Study**

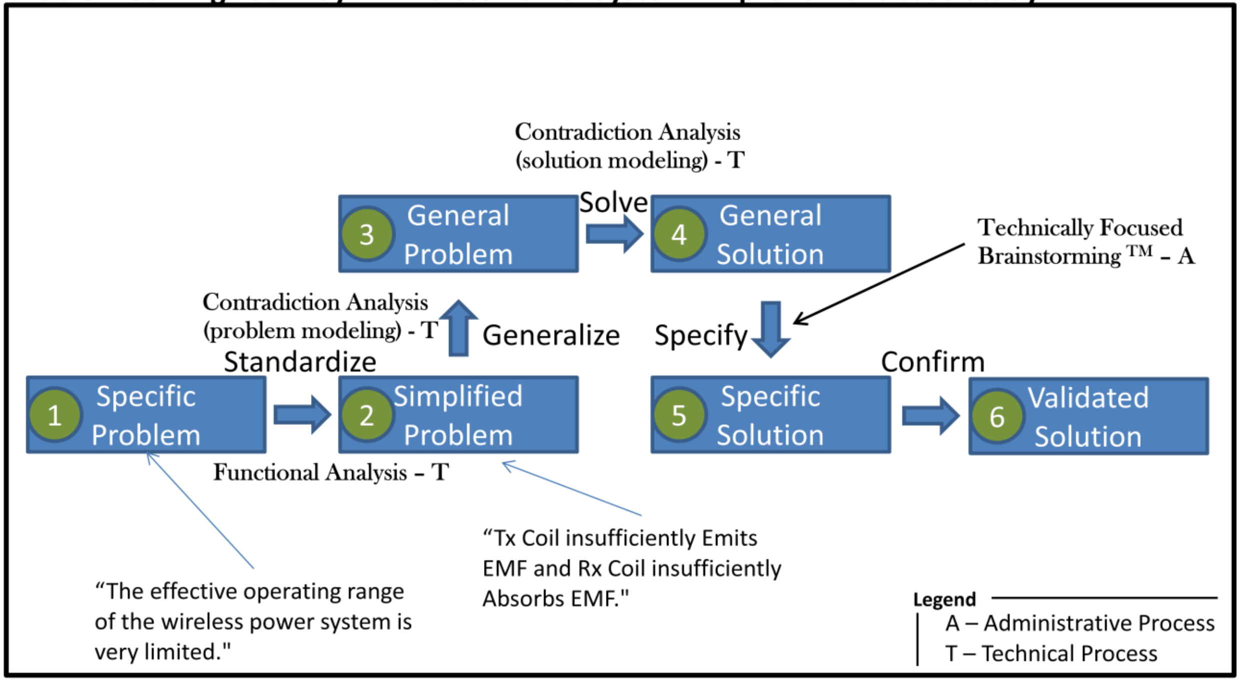


Figure 17

**Wireless Power System Schematic**

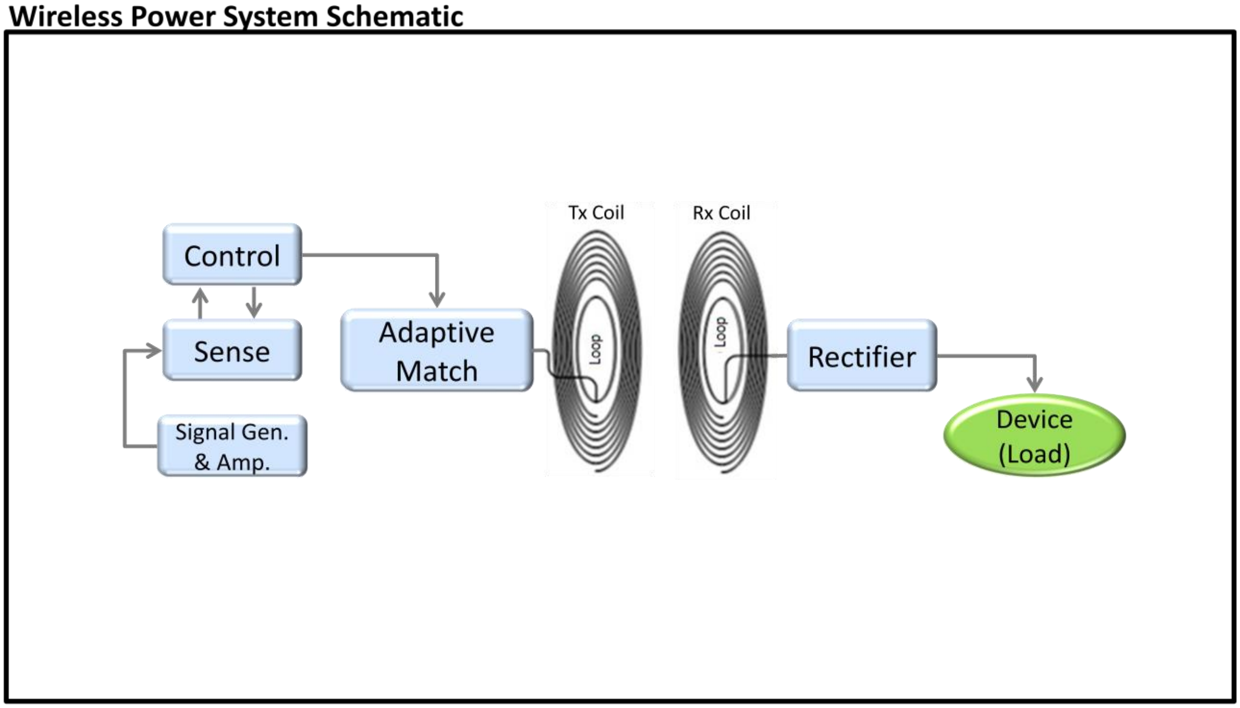


Figure 18

**Wireless Power System Functional Model**

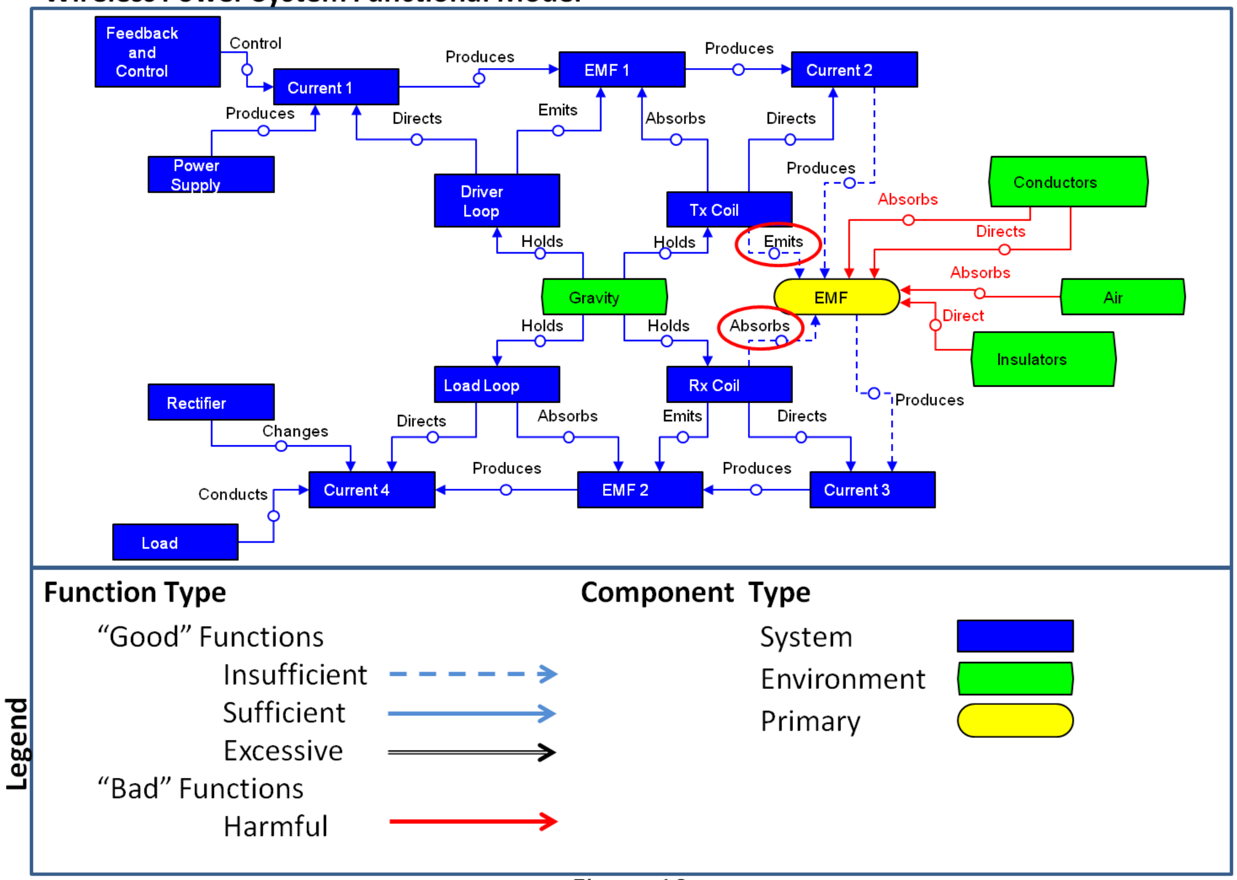


Figure 19

power up to several meters. Such a system can even work over greater distances if the coils are even larger. Because of the frequency, wavelength and power levels used in these systems a human can even walk into the path of the beam with no adverse effects while modestly sized piece of equipment can be run by way of the invisible beam. The challenge of improving the system is the limitation in size of one or both of the coils based on the form factor (size and shape) of the device (i.e., cell phone) intended to take advantage of the wireless power source. Imagine a wirelessly power smart phone where the receiver coil is place just inside the smart phone's case limiting the coil to a diameter of approximately 5 centimeters. Such a system would most likely be limited to an effective charging range of no more than 15 centimeters.

Therefore, the transition from step one (specific problem - "the effective operating range of the wireless power system is very limited" to step two (simplified problem - "Tx Coil insufficiently Emits EMF and Rx Coil insufficiently Absorbs EMF") (see Figure 17) was completed using Functional Analysis. Next, the transition from step two (Simplified Problem) to step three (general problem) was completed by way of contradiction analysis. The simplified problem of "Tx Coil insufficiently Emits EMF and Rx Coil insufficiently Absorbs EMF" can be analyzed in so far as the size and orientation of the transmission and receiver coils. Large coils (see large blue circle represented in Situation 1 of Figure 20) would transmit over long distances (see large orange circle represented in Situation 1 of Figure 20) but would require the device transmitting the power and the device receiving the power to also be very large (see large

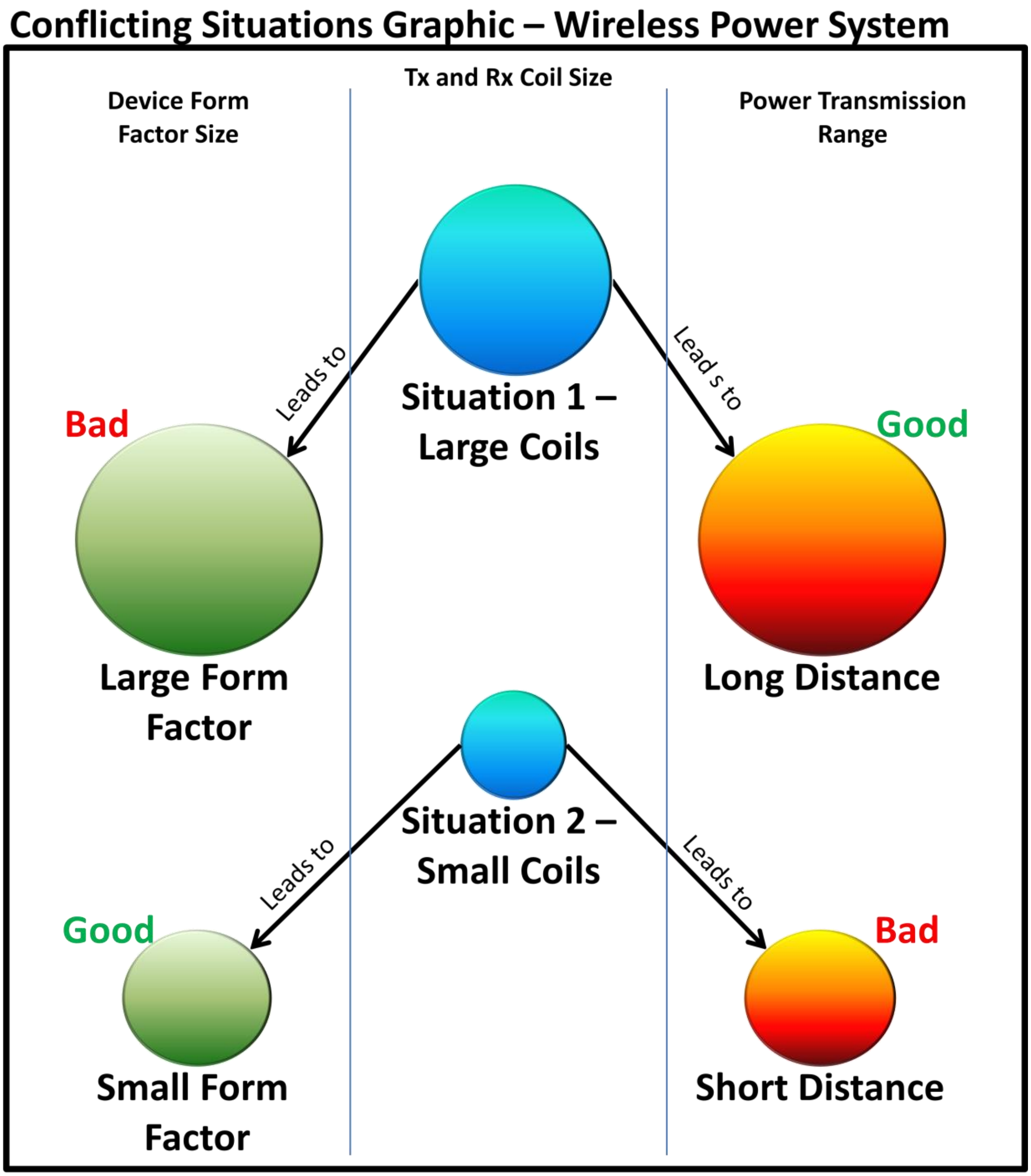


Figure 20

green circle in Situation 1 of Figure 20). On the other hand small coils (see Situation 2 in Figure 20) would be much less effective at transmitting power (see small orange ball in Situation 2 of Figure 20) but would allow the transmitting and receiving devoices to have small form factors (see small green ball in Situation 2 of Figure 20) since the coils would be small. Once again referring to Figure 17, the transition from step three (general problem) to step four (general solution) is represented by the merger of the two desirable results from the problem models created by some yet to be determined system design.

Therefore, the abstract model that solves this contradictory requirement for the coils to be both large and small simultaneously would look like the diagram in Figure 21. The "unknown solution" or General Solution (represented by the large white circle - Figure 21) would result in small device form factors (represented by small green circle) while simultaneously providing long distance power transmission (represented by the large orange circle). The General Solution (see step 4 of Figure 17) should create the "good" effects represented within the two differing problem models (small form factors and long-range power). Next, utilizing Technically Focused Brainstorming ™ (Figure 17) to transition the methodology from step four (general solution) to step five (specific solution) I developed specific solutions that transcended the system's contradictory requirements, as reflected in the associated contradiction analysis, and simultaneously increased the system's value. While more than 35 solutions were actually developed to address the contradictory system requirements only a few are shared in this case study. First, and decidedly most simply, is to use flip up an/or fold out coils that can be expanded when power transmission is necessary. This keep the system's form factor small during battery power (or mobile) operating modes but still allows for effective power transmission during charging states. Solutions two, three and four are most complex and would require some technology development but completely solve the contradiction of needing both large and small cols for the system. Since the coil size is driven by the physics of electricity it would be prudent to find another way to charge a remote device without the use of transmitted power. For example, instead of transmitting power and therefore needing large system coils, it would be possible to create power at the receiving device by the use of other transmissions. The first possibility is to transmit a different type of electro-magnetic propagation that instead of being the actual power source, creates power at the receiving device by moving ferrous balls in an oscillatory fashion within a linear electric motor to create power where needed instead of transmitting that power. This eliminates the need for large transmission and receiver coils. A massively parallel array of these linear electric generators could be used to create the necessary device voltage for operation. The third and fourth solution concepts operate in a similar manner of creating power at the receiving device but use sound and heat as the triggering medium. In each case a nano-material (the first sound sensitive and the second heat sensitive) is used to convert transmitted sound or heat into electrical power at the receiving device. This once again meets the requirements of "transmitting power" but avoids the need for large coils in doing so.

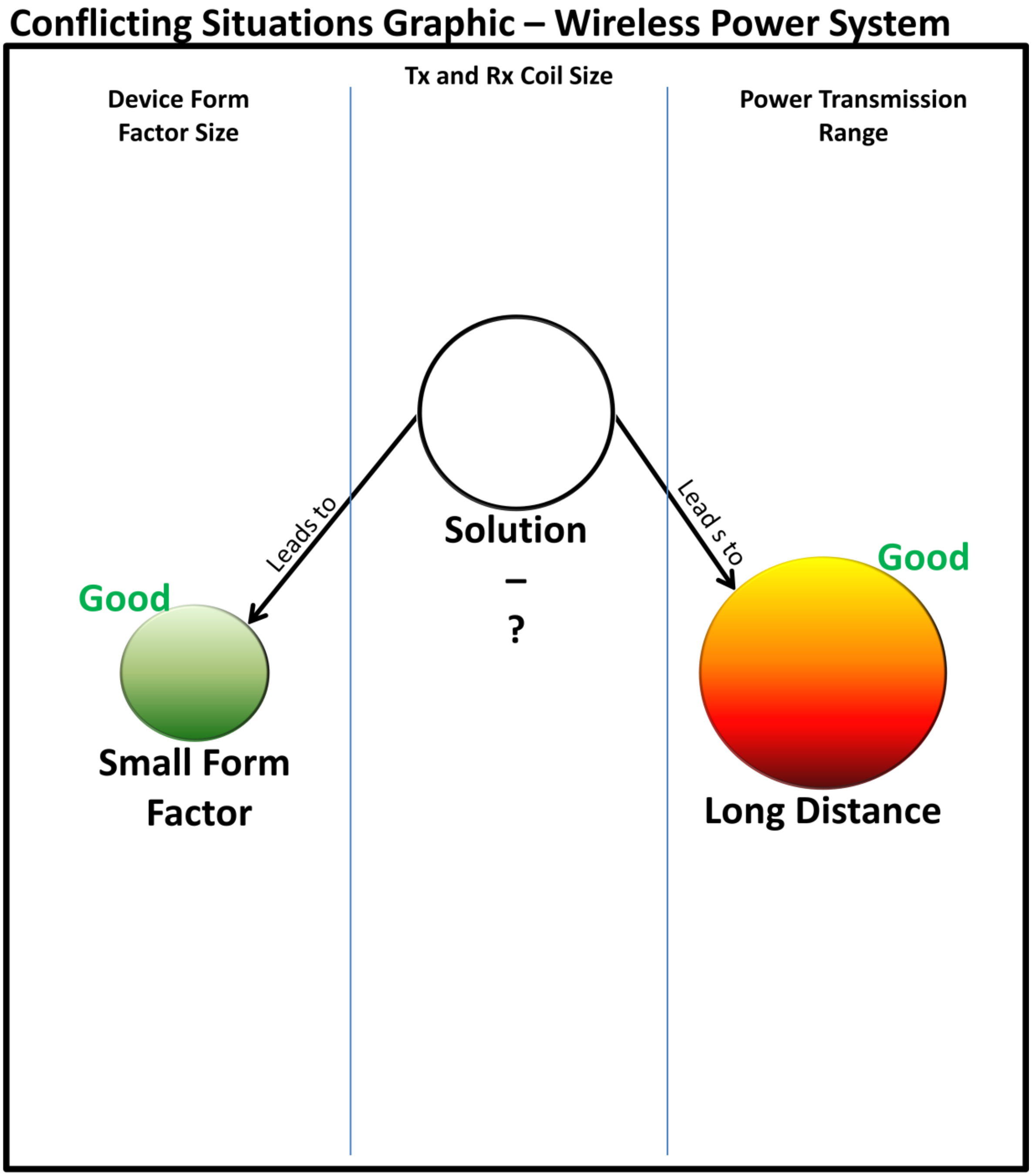


Figure 21

**Conclusion**

There are dozens if not hundreds of problem-solving methods in use today. None of them are solely capable of providing all of the necessary steps for effectively solving problems. Further, only a couple of these methods are capable of creating innovative solutions to complex problems even though those methods still require other processes to round out their capabilities. By combing multiple methods (Figure 13), which have complimentary sets of strengths and weaknesses, complete and effective processes can be created which not only provide the resources necessary in effective problem solving but also allows for the generation of innovative solution concepts.

The Problem-Solving Pathway contains six steps for effective problem solving:

1.) Specify a problem

2.) Simplify the problem

3.) Generalize the problem

4.) Generalize a solution

5.) Specify a solution

6.) Validate the solution

Different problem solving and innovation methodologies are useful as process engines at different points of the Problem-Solving Pathway (Figure 12). In order for a solution to be innovative it must solve a contradictory demand placed upon a system. To model and solve these system contradictions contradiction analysis must be utilized when transitioning from step two to step three and from step three to step four of the Problem-Solving Pathway. With a little planning and an understanding of how differing methods provide different capabilities a very wide range of problems can be addressed with the generation of innovative solutions.

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# Problem Solving Methodology Review Summary - David Conley

## Summary of Techniques as Problem Solving Tools

| LI# | Tool/Method | Primary Focus | Administrative (A) Technical (T) | Solution Generation Tools? | Pros | Cons |
|---|---|---|---|---|---|---|
| 1 | Brainstorming | Spontaneous generation of solutions | A | Yes | Rapid and extensive solution generation | Process is marginal at generating effective and workable solutions especially if the brainstorming is not focused on a well defined model of the root problem |
| 2 | Contradiction Analysis (TRIZ) | Analyzes contradictory requirements within a system | T | No | Allows the problem solver to view a problem in its most elementary state in order to fully understand what within the system is making contradictory demands of the system | If the problem solver does not already have a good understanding of the system components, or root causes, that are responsible for the contradictory demands on the system then a methods must first be employed to identify the contradictory system limitations |
| 3 | Functional Analysis | Structured representation of functionality | T | No | Combines textual information (components and functions) with a graphical format (functional mapping) to create a visual record of how a system operates and what its strengths and weaknesses are | Has no solution generation tools to support elimination of the initial issue |
| 4 | Kepner Trego | Alternative selection by way of numerical scoring | A/t | No | Provides a quantitative method that supports root cause determination | Has no tools in support of the development of solutions (changes), innovative or otherwise. |
| 5 | Lean | Waste Elimination | A/t | No | Focus on waste reduction, opposed to a general focus on problem solving, and has somewhat well defined operating definitions and guidance | Non-system level approach and the inability to thoroughly technically direct the problem solver in waste elimination |
| 6 | PDSA Cycle | Change Testing | A | No | Guidance it provides to the planning in understanding how changes made to a system effect that system and the guided response to the measurement of the change effect | Has no tools in support of the development of solutions (changes), innovative or otherwise. |
| 7 | RCA (root cause analysis) | Root cause identification | T | No | Combines textual information (reasoning) with a graphical format (RCA mapping) to create a visual record of what situations are contributing to an issue. Further this visual record also reveals the relationships between the various RCA paths (chains) so that convergent solutions can be applied often creating more efficient solution paths | Has no solution generation tools to support elimination of the initial issue or the identified root causes |
| 8 | Six Sigma (DMAIC & DMADV) | Variation reduction | A/t | No | Ability to capture analysis requirements for success, the quantification of system performance levels from before and after changes have been implemented, and the focus on follow-up and continuous monitoring | The fourth step of both DMAIC (Improve) and DMADV (Design) are poorly, if at all, supported by any technical processes within the mainstream usage of Six Sigma. In other words, the problem solver is instructed to improve and design at this step but left pretty much up to their own devises in how exactly to do so |
| 9 | Su-Field Analysis (TRIZ) | Abstraction and qualification of substance and field interactions | T | Yes | Breaks mental inertia by suggesting specific and proven solution paths based on the structure of the initial problem model | If the problem solver does not already have a good understanding of the system components, or root causes, that are responsible for the contradictory demands on the system then a methods must first be employed to identify the contradictory system limitations |
| 10 | Systems Engineering | identified properties of systems as a whole | A/t | No | Combines textual information (components and functions) with a graphical format (functional mapping) to create a visual record of how a system operates and what the system's useful and harmful functions are | Has no solution generation tools to support elimination of the identified issues |
| 11 | Technically Focused Brainstorming | Targeted solution generation | A/t | Yes | Guides the problem solver to create solution concepts that will resolve system contradictions and improve the value of the system under analysis | Can only be applied in problem solving efforts where Contradiction Analysis and resolution has been completed |
| 12 | Trends (TRIZ) | Guiding advancements based on empirical data regarding historical changes to similar systems | a/t | Yes | Accurate method of "seeing" upcoming changes to systems | Links between various trends is weak and application algorithms do not exist for all trends |
| 13 | Six Thinking Hats | Structuring human thought based around 6 specific "Brain Challenges" allowing individuals to develop tactics for thinking about particular issues | A | No | Guides parallel thought process for groups of people and supports the consideration of a variety of view points | Has the potential to create conflict if not well facilitated and does not insure a structured or repeatable process in focusing on root causes or effective solutions |
| 14 | Inventive Principles (TRIZ) | Complete set of methods used to resolve contradictory system requirements | T | Yes | Reduced mental inertia by focusing problem solver on successful solutions to system challenges | Can only be applied in problem solving efforts where Contradiction Analysis has been completed |