Abstract

GILBERT, ELANA. Integrating Accelerated Problem Solving into the Six Sigma Process Improvement Methodology (Under the direction of TIMOTHY CLAPP)

Six Sigma has revolutionized the world of business and has presented a new measure of success in customer satisfaction and quality. Six Sigma uses an array of statistical and analytical tools to apply a data-driven, root-cause analysis to existing processes to minimize variation and aim for zero defects. The purpose of this thesis is to study the purposes, tools, goals of Six Sigma’s scientific discovery process and find areas conducive to the integration of accelerated problem-solving techniques, in hopes of deriving a more complete methodology.

A typical Six Sigma project may encounter a variety of issues that either stem from or contribute to the process problem of the project's focus. The problem solving theory presented in this thesis discusses these issues in terms of the dimensions of problem solving which are orientation level, solving stage, and tool/problem type. Viewing Six Sigma in the light of this theory revealed a need for the addition of tools that addressed issues associated with personnel and belief system limitations, “stuck thinking”, and innovative solution generation.

The accelerated problem-solving tools integrated to address these issues are as follows: Six Hats Thinking, Mind Mapping, elements of the Theory of Inventive Problem Solving (TRIZ), the Theory of Constraints (TOC) and elements of
Kepner-Tregoe’s management model. A hybrid Six Sigma model was developed to address each dimension of problem solving.

The new model was applied during a Six Sigma Green Belt project at a nonwoven manufacturing facility. The author acted as a Six Sigma Coach to the team and used accelerated problem-solving tools to address obstacles in project progress and thinking. The hybrid model was useful in increasing the quality of communication among team members, providing breakthroughs in thinking and promoting the use of the existing DMAIC tools.
INTEGRATING ACCELERATED PROBLEM SOLVING INTO THE SIX SIGMA PROCESS IMPROVEMENT METHODOLOGY

by

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BIOGRAPHY

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Following graduation, Elana hopes to pursue a Ph.D in business and public administration.
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Chapter One

Introduction

What does it take to survive in business today? How does one stay afloat in a fluctuating economy flooded with change, a growing demand for low cost, high quality and minimal time to market? The answer: maintaining a competitive edge. Any business management professor would agree that in order to stay appealing to the consumer market, one must anticipate the customer, improve process efficiency and effectiveness in order to lower cost of production while achieving high quality standards.

How does a company stay competitive? With buzzwords and phases such as “innovation”, “total quality” and “thinking outside the box”, the consultant market has been flooded with those offering to pave the way to managerial and process improvement breakthroughs. In the last thirty years, ever since the dynamics in the global market began to shake the American concept of quality and manufacturing practices, methodologies such as TQM, Global 8D, Lean, and now Six Sigma have come to the surface to provide structured habits to insure quality and efficiency, promising gains and results. In the last ten years, Six Sigma has become the methodology of choice when attempting to achieve advances in revolutionary quality and streamlined business practices. Its simple, yet structured approach and its emphasis on using the existing human network within a company to drive for results that impact the bottom line, make Six Sigma stand out from its quality predecessors.
In 1987, Motorola launched the concept and practice of Six Sigma [26]. Mikel Harry, an engineer and trained statistician, began to study and apply the concepts of process variation developed by W. Edwards Deming in order to find ways to reduce variation in order to improve performance. The “sigma approach”, named for the standard unit of variation around the mean, caught the attention of Bob Galvin, CEO of Motorola, and soon became the “way of doing business at Motorola.” With an emphasis on continuous improvement as well as a continuous aspiration toward perfection, “Motorola adopted a Six Sigma goal in everything they did, roughly equivalent to a process producing only 3.4 defects […] per million opportunities; near perfection”[16].

The practice of Six Sigma addresses and identifies the sources of “common cause variation” as well as variation due to occasional or special causes. Employing a long list of preexisting statistical, analytical and quality techniques, Six Sigma empowers members of an organization to improve processes and services throughout the organization using a logical, systematic, problem identification method to meet the organization’s financial objectives and mission statements. Although the tools and techniques have been around for quite some time, this method’s layout and infrastructure prescription for the members of an organization, enable Six Sigma to bring sustainable success through changing a company’s culture and the way its business is done.

The claims of phenomenal success using this approach have been repeatedly echoed and validated by bottom-line results reported particularly by Bob Galvin of Motorola, Jack Welch of GE, Larry Bossidy of Honeywell/Allied
Signal, and countless others. During the decade after the birth of the Six Sigma concept, Motorola saw a “five-fold growth in sales, with profits climbing nearly 20 percent per year; cumulative savings based on Six Sigma efforts pegged at $14 billion…stock price gains compounded to an annual rate of 21.3 percent” [41]. Soon to follow in business breakthrough was the already strong, very profitable GE, the merged Allied Signal/ Honeywell, which mirrored the turnaround success of Motorola, as well as a host of other companies varied in background and industries. Like Motorola and GE, companies that credit Six Sigma with their major success launched the philosophies, tools, and practices with support, initiative, and adequate training from top management down to the associates on the production floor.

Even with Six Sigma’s staggering success and development, process improvement and management transformation is only the halfway mark for the goal of staying competitive. What is the next step? The answer lies within a quote by charismatic CEO of General Electric Company. Jack Welch, CEO of General Electric, says, “If the rate of change inside the institution is less than the rate of change outside, the end is in sight. The only question is the timing of the end” [55]. The next step is innovation.

From his book, Creativity, Innovation, and Quality, Paul E. Plsek cites five compelling reasons why the members of any organization should interest themselves with innovation and creativity [43]. The first is associated with the bottom-line: “Superior long-term financial performance is associated with innovation.” The second has to do with the client: “Customers are increasingly
demanding innovation.” The third touches on the competition: “Competitors are getting increasingly better at copying past innovations.” The last two reasons address the past and the present respectively: “New technologies enable innovation” and “What used to work, doesn’t anymore” [43]. These reasons speak to any company’s most significant focal points and what is on the mind of every CEO: financial performance, the customer, the competition, where they were and where they are going. Adopting a proven method of innovation will give an organization a tactical approach to stay ahead of the competition, anticipate the customer, thrive financially, learn and build off of past success and failures, and direct a path into the future.

To stay successful and insure future success, Plsek says that companies must streamline to cut cost, provide quality, and creatively innovate [43]:

“The question of whether an organization should focus on quality management or creative thinking…is the wrong question. More to the point, or is the wrong conjunction. Organizations today are challenged to focus on quality and creativity…all at once…because creativity and innovation contribute to organizational success. And that is what we should all be focused on. “

The idea of simultaneously focusing on quality (or process improvement) and creative innovation via method integration is one of both logical progression and growing interest. The reasoning for the point that Plsek makes in the above quote can be missed if not for the explanation he makes in the prologue: “there are limits to traditional analytical thinking when it comes to solving nagging
problems or generating breakthrough ideas. What we need it seems, is the ability to be analytical when the situation calls for it and creative when the situation calls for that. Both skills are critical for success”[43]. Without necessarily realizing the simple, yet profound logic ascribed by Plsek, many have already begun to contribute toward a movement to systemize and to integrate both process improvement and innovation to make them more easily and more routinely implemented. Six Sigma has come forward as the first, clearly systematic process improvement strategy, leaving verifiable success in its wake. Innovative techniques such as brainstorming, Mind Mapping, Six Hats and TRIZ are some of the successful structured results for accelerating and improving problem solving. The integration of systematic innovation techniques into an effective process improvement methodology has the potential for a more robust, more powerful, and a more complete approach, thereby attacking problems from both an analytical and creative approach. Employment of such a methodology would lead to faster, exceptional results that would take competition to a whole new level, putting practitioners on the forefront.

The purpose of this thesis is to find a useful model to integrate some of the more efficient innovative problem-solving techniques into an effective process improvement strategy for a more complete methodology that will aid in maintaining a competitive edge. This thesis will explain how the integrated problem-solving methodology was developed, weaving elements of TRIZ, Six Hats Thinking, Kepner-Tregoe, Theory of Constraints, Mind Mapping and brainstorming into the existing Six Sigma structure. Chapter Two will examine
Six Sigma literature, as well as take a closer look at the DMAIC problem-solving model of Six Sigma. Chapter Three will survey the structure of the selected innovation tools, respectively, in search of the best areas for a complementary fusion of techniques. Chapter Three will end with a justification of the selection of the tools chosen versus the many that are available. Chapter Four will introduce the integrated method and explain the placement of certain tools based on the potential impact on the user and the process. The last two chapters will describe the proceedings and report results of a case study wherein the derived model was implemented. The report of this case study will include the impressions and reactions to the effectiveness of both Six Sigma and the innovation tools embedded in the derived model.
Chapter Two
Six Sigma

2.0 Introduction

Six Sigma’s success has been attributed to embracing it as an improvement strategy, philosophy and a way of doing business. This chapter will discuss Six Sigma in terms of definition, history, implementation and experiences in order to construct a well-rounded profile of the methodology. In doing so, this chapter will justify the use of Six Sigma as a foundation for integration. This chapter will then take a closer look at Six Sigma’s process improvement model, DMAIC, highlighting areas that may have room for innovative tool incorporation.

2.1 Six Sigma

2.1.1 Definition. There are many offerings for the definition of Six Sigma, each one addressing one of the several aspects of its phenomenon of the pursuit of “near-perfection in meeting customer requirements” [41]. To be strictly statistical, it involves “operating with only 3.4 defects for every million activities or ‘opportunities’” [41]. In business terms, “Six Sigma is a smarter way to manage business or a department. Six Sigma puts the customer first and uses facts and data to drive better solutions” [40]. Combining the preceding definitions, one could say that Six Sigma is a data driven, process improvement, problem identification tool that uses both the scientific method and statistical analysis to achieve bottom-line results. On the surface, the merging of these two definitions into one would typically suffice. However, looking at what defines Six Sigma from
a more holistic view is important to fully appreciate its potential impact on the overall profitability of an organization.

For example, to the customer, Six Sigma means higher quality at a better price. One of the most significant characteristics of Six Sigma is its concept or “theme” of customer focus. From the very beginning of a typical Six Sigma project, the practitioner, usually a Black Belt, chooses metrics and deliverables that drive customer requirements and demands. These goals are known as CTQs (critical to quality). This approach of “beginning with the end in mind” sets Six Sigma up to directly benefit customer every time. In his book, *The Six Sigma Revolution*, George Eckes relates a “then and now” account of his experience with the airline industry [16]. By the end of his story, he makes the point that many companies forget the reason why they are in business: the customer. Six Sigma helps to bring that point back into focus by not only reintroducing a drive to please the customer, but also by aligning customer demands with primary business objectives.

To the employee, Six Sigma is empowerment and a game plan. Often in manufacturing and service settings, associates and floor managers find themselves constantly frustrated “putting out fires”, dealing with the constant onslaught of emergencies, rework and the “gremlins” inherent to the process, all without attacking the real, recurring root-cause of the problems within the process. Six Sigma as a methodology provides a logical sequence of steps to uncover vital knowledge about the service or manufacturing process in question. To quote from Jonathan Andell, author of the article, “Benefiting from Six Sigma
Quality”, who paraphrased some Motorola pundits, “If we can’t quantify it, we can’t understand it. If we can’t understand it, we can’t control it. If we can’t control it, it controls us” [46]. Finding the information that leads us to the root causes puts an end to the blame game, covering mistakes, and ultimately, minimized variation. Six Sigma provides a systematic method to find, quantify and “translate that knowledge into opportunities for business growth,” and well as power over the process [8].

To senior management, and eventually the whole organization, Six Sigma is a cultural change. Six Sigma is not simply a set of tools or another quality program; rather, it is “a way of doing business” [55]. Pande, Neuman, and Cavanaugh, the authors of The Six Sigma Way, put it this way: “Still another way to define Six Sigma is as a sweeping “culture change” effort to position a company for greater customer satisfaction, profitability, and competitiveness” [41]. The above viewpoints echo the six themes of Six Sigma, which are outlined in The Six Sigma Way. They are:

1. Genuine Focus on the Customer
2. Data- and Fact-Driven Management
3. Process Focus, Management, and Improvement
4. Proactive Management
5. Boundaryless Collaboration
6. Drive for Perfection

These six themes are the heart of the Six Sigma philosophy and shape the definition and practice of Six Sigma as a methodology.
2.1.2 History. Six Sigma is more than a philosophy, a defect rate, or cultural change; it is also a new way of doing business. In 1985, Motorola launched the concept and practice of Six Sigma [26]. Mikel Harry, an engineer and trained statistician began to study the process variation concepts developed by W. Edwards Deming in order to find ways to reduce variation in order to improve performance. The “sigma approach”, named for the standard unit of deviation of variation around the mean, caught the attention of Bob Galvin, CEO of Motorola, and soon became the widespread business practice at Motorola [19]. With an emphasis on continuous improvement as well as a continuous aspiration toward perfection, “Motorola adopted a Six Sigma goal in everything they did, roughly equivalent to a process producing only 3.4 defects …per million opportunities; near perfection”[19].

During the decade after the birth of the Six Sigma concept, Motorola saw a “five-fold growth in sales, with profits climbing nearly 20 percent per year; cumulative savings based on Six Sigma efforts pegged at $14 billion…stock price gains compounded to an annual rate of 21.3 percent”[16]. An article entitled, “In the Beginning”, by Blanton A, Godfrey, reports an interview with Bob Galvin, detailing his reflection on the start and evolution of Six Sigma [19]. During the interview, Galvin explains that the key to leading this initiative at Motorola began with him listening to the customer, despite the fact that at the time, “In this business we had 85% of the world’s market share and were getting double digit growth.”
After Motorola started to share their new practices with others, Larry Bossidy of Allied Signal begin to experience success with this continuous improvement practice after launching Six Sigma in 1994. The Six Sigma program’s success is evident in the $2 billion-plus in savings and 988% growth in stock price Honeywell has enjoyed [28]. After asking Bossidy, a former employee of GE, about his successes, Jack Welch, CEO of GE, announced the beginning of their corporation-wide initiative in 1995. Roger Hoerl of General Electric Co., explains the launch and evolution of Six Sigma at GE in his article, “An Inside Look at Six Sigma at GE”[27]. This article reveals that much of the structure, best practices, certification titles and requirements commonly outlined in the training arena today occurred at GE during its Six Sigma deployment. Because of their effort, GE experienced an improvement in operating margins from 13.6% to 18.9%; a move in inventory turns from 5.8 to 8.5, and a doubling in earnings per share over the five years of implementing Six Sigma. GE also experienced “an asset efficiency (ratio of plant and equipment expenditures to depreciation) moving down toward 1.0 (with future movement projected to 0.8—which indicates finding free production capacity concealed among current corporate assets by removing the “hidden factories” caused by waste and rework)” [55].

2.1.3 Implementation. Most of the literature concerning Six Sigma focuses on successfully implementing Six Sigma practices into one’s organization. Implementation comes in one of two models: tool-based and projected-based [6]. Tool based implementation focuses on “the mechanics of tool execution, as
opposed to when and how a tool should be implemented and integrated with other tools.” Project-based implementation involves tools being “taught and then applied to projects that are defined before [training] sessions begins.” Aspects of project-based implementation will be the focus of this section since it is the most widely used by Six Sigma trainers and thought to be the most effective [21]. Many organizations “can achieve more significant bottom-line benefits with this approach,” as it reflects more use of the themes of Six Sigma, as mentioned earlier [6].

Most of the texts that touch on training echo the description outlined by Mikel Harry. He describes a training that is project-based, in that it follows the Plan-Train-Apply-Review (P-T-A-R) model, where trainees learn the Six Sigma philosophy, theory, tactics and tools and immediately apply them in a project that was selected for them prior to the start of training [26]:

“Black Belts spend one week learning each phase of the Breakthrough Strategy with three weeks between each of the four weeklong sessions to apply their knowledge of the phase they have just learned to their assigned projects. Training extends over a four-month period, with project reviews in Week Two, Week Three and Week Four.”

Because of the learn-while-doing approach, Black Belts and Green Belts are able to make a significant impact on current business issues and practices during their first project, learning more about their customer, process and business
environment. The practical teaching and simultaneously application allows for a quicker return on investment in training and personnel.

2.1.3.1 Infrastructure. Infrastructure is one of the most important issues that need to be addressed when employing a project-based approach. A supportive infrastructure should be in place prior to the deployment of a Six Sigma initiative. Although there are several parts of the infrastructure, the most important is the executive leadership [6]. What is often misunderstood about starting a Six Sigma initiative is that it is another quality program that has to be executed by a separate management team or quality department. However, a successful organizational initiative begins with the “commitment and leadership of their management” as evidenced by GE, Honeywell, and a host of other companies [6]. The authors of Managing Six Sigma identify twelve components of the “successful Six Sigma infrastructure”, the first of which (executive leadership) has already been discussed. The eleven others can be addressed by following the eight essential steps of Business Process Management, as outlined in the book, The Six Sigma Revolution by George Eckes. These steps make up the strategic business component of Six Sigma and are designed to enable executive leadership to “create the infrastructure for Six Sigma to be successful in an organization” by translating the function or departments of the organization into key processes or services through an intense customer focus [16]. These eight steps are:

1. Creation and agreement of strategic business objectives
2. Creation of core/key sub- and enabling processes.
3. Identification of process owners

4. Creation and validation of the key measures of effectiveness and efficiency for each process (as known as “dashboards”)

5. Collection of data on agreed dashboard

6. Creation of project selection criteria

7. Using the project selection criteria for project selection

8. Continual management of processes to achieve strategic objectives of the organization.

The execution of these eight steps will authenticate management’s commitment to the initiative as well as provide the planning, communications, and the cultural change needed to have sustained success with Six Sigma.

2.1.3.2 Deployment. Nearly all of the texts discuss in some regard the issues surrounding deployment. The most direct discussions can be found in a book written by Mikel Harry, Richard Schroeder and Don Linsenmann titled, Six Sigma: the Breakthrough Management Strategy Revolutionizing the World's Top Corporations. In the chapter, “Implementation and Deployment” they discuss how to develop a “proper” deployment plan, criteria to select an effective training provider and several suggestions for trainee to personnel ratios. Proper deployment, as described by Harry et al., consists of training both Black Belts (BBs) and Green Belts (GBs) in waves and launching several projects simultaneously, after designating process owners, champions, and a reward system for achievements made using Six Sigma [26].
From Art to Science is a business novel that gives an illustration of such a roll out, from beginning to end.

Repeatedly stressed throughout Six Sigma texts is the need for “top management involvement and visible support” as well as the need to think of Six Sigma as an investment [47]. The idea of deployment suggests that the organization as a whole, be it an entire corporation, a division or a department, is in the process of becoming a “Six Sigma organization”, intending to change the way they do business. Yet, many organizations are prone to launch their Six Sigma efforts without making a serious commitment [40]. Making the investment in Six Sigma involves committing full-time Black Belts and/or Master Black Belts to Six Sigma activities and selecting projects that are important, visible and tied to the corporate (or organizational) objectives [21].

There are also several misunderstandings of how to practice Six Sigma, as well as what to expect from that practice. Most of the texts that look at the whole Six Sigma experience address mistakes made when deploying an initiative and how to avoid making a launch ineffective. For example, the authors of The Six Sigma Way offer “Twelve Keys to Success”. Among those are [47]:

- Tie Six Sigma efforts to business strategy and priorities
- Make an investment to make it happen, and
- Make top leaders responsible and accountable

In his article, “Six Sigma Program Success Factors”, Mark Goldstein of Goldmark Consultants, Inc., lists the following program success factors [21]:
1. Deployment plan. “The lack of understanding of this fundamental point (or lack of experience in developing a deployment plan) is a primary factor that contributed to the failure of some of the earlier quality improvement programs.”

2. Active participation of the senior executives. Goldstein describes what is meant by active participation by upper management why it is so critical to the longevity of an initiative.

3. Project reviews. “If reviews are conducted on a regularly scheduled basis, the process maintains constant, steady pressure on the BBs and Green Belts (GBs) to drive their projects to a successful completion and closure. Reviews provide oversight to make sure that the BBs and GBs are correctly following the Six Sigma strategy and methodology. They ensure proper use of the Six Sigma tools.”

4. Technical support (Master Black Belts).

5. Full-time vs. part-time resources.

6. Provide adequate training.

7. Communications.

8. Effective project selection.


10. Institute an incentive program.

11. Provide safe environment.

12. Develop a supplier plan.
13. Customer “WOWS”

Goldstein and others suggest that using the tips and techniques that they outline will help companies avoid the pitfalls that are associated with managing change and getting an organization on board with effective program implementation.

As previously mentioned, Mikel Harry expressed concern about proper deployment and reiterates that point by writing *Six Sigma Knowledge Design*. He asserts that the key to setting up the infrastructure that will lead an organization to breakthrough success is to have a “six sigma knowledge architecture” in place. In other words, the organization must make a commitment to truly understand the “relative context, framework, and mitigating factors that should be fully weighted and considered when designing and developing six sigma curricula” [25]. He states, “If six sigma is about quantum change—and it most certainly is—then we need a carefully designed fabric of interactive ideas that are capable of structuring, unifying, and inspiring each separate mind in a corporation, particularly those that are directly involved in and responsible for deploying, implementing, and achieving ambitious business aims” [25]. This book provides what the author denotes as ten “filters” for assessing of how well an organization embraced the philosophies of Six Sigma when constructing its infrastructure.

2.1.4 Scientific Discovery Process. Six Sigma’s keystone methodology, a derivative of Deming’s PDS(C)A cycle, is made up five phases: Define, Measure, Analyze, Improve and Control. These phases and their distinct characteristics give Six Sigma its structure and clarity. As practitioners step through each phase, they apply the scientific method to their process in order to find the root cause of
either special or common cause variation. They systematically examine a process problem by first clearly defining the problem, deliverables, measures, and measurement system, and then, verify the measurement system in place. Next, that practitioner continues by finding the root cause of the problem, improving the system and finally, holding gains achieved. The practitioners, who are usually Black Belts or Green Belts, may utilize a combination of several different statistical and analytical tools to achieve the goals of each phase.

2.1.5 Experiences. Two articles in *Six Sigma Forum* magazine relate in detail the experiences of an organization as it reached its goal of becoming a Six Sigma organization. That organization is General Electric Company and the articles are “20 Key Lesson Learned” by Gerald J. Hahn and “An Inside Look at Six Sigma at GE” by Roger Hoerl.

Hahn begins his article by explaining that his list of lessons learned is a work in progress as well as a summation of lessons from Motorola and his experiences at GE. Among the lessons learned he lists [23]:

- Start when the time is right: that time is now
- Develop an infrastructure
- Commit top people
- Select initial projects to build credibility rapidly
- Plan to get the right data, and
- Keep the toolbox vital

“An Inside Look at Six Sigma at GE” by Roger Hoerl is an excerpt from the book *Leading Six Sigma*, with he co-authored with Ronald Snee. He begins this
excerpt by pointing out the “following erroneous conclusions” that many have made about GE phenomenal success with Six Sigma [27]:

- GE’s Six Sigma deployment was easy (it wasn’t).
- External consultants showed us how to do everything (they didn’t).
- Nonmanufacturing and design applications came at the very beginning (they came later).
- GE didn’t make any mistakes along the way (it did).

Hoerl goes on to share a personal account of how Six Sigma unfolded at GE in the five years that Jack Welch (CEO) projected. A few weeks after Welch’s announcement, Hoerl attended Master Black Belt training, during which he noted the commitment of all of the participants present. He relates [27]:

“No one debated over the merits of Six Sigma or asked if the reported results from AlliedSignal or Motorola were real. No one wondered if Six Sigma would apply to GE or if this was just a repackaging of total quality management. Rather than debating these questions, virtually all the MBBs asked questions about how to implement it as quickly and effectively as possible.”

Hoerl goes on to comment that some leaders at GE did retain skepticism concerning Six Sigma, and subsequently left the company: “While such actions may seem severe, it goes back to something that Jack said: If executives could not support Six Sigma 100%, GE was simply not the right company for them…We had to focus on implementation. Leaders had to lead” [27].
Hoerl’s article illustrating some of the lessons listed in Hahn’s article by relating some of the mistakes and modifications that GE made to the Six Sigma methodology, as well as tips on how to apply Six Sigma to finance. He concludes his article by emphasizing that application of Six Sigma was “not easy”, and therefore required commitment, resources and vision by making the following assertions [27]:

- “…[GE] was doing quite well financially when it embarked on Six Sigma…Why wait until you have a crisis before you start improving?”
- “Senior leadership, especially Jack Welch, provided unyielding commitment to the initiative going and ensured continued success. This will not be easy for other companies to copy.”
- “Some of the best people in the company, in virtually all business functions, were freed from their normal duties to focus 100% on Six Sigma.”
- “Lastly, GE used a formal and structured deployment plan that included the required infrastructure (the Six Sigma organization, project selection systems and benefit verification systems).

2.1.6 Six Sigma vs. TQM. Many ask, “How is Six Sigma different from TQM?” Jonathon Andell, author of the article “Benefiting from Six Sigma Quality”, said, “Six Sigma is not a new philosophy, a new set of problem-solving tools, or a
new expert skill level. In fact, many highly effective Six Sigma practitioners appear to have repackaged prior offerings under this popular title!” [46]. Andell is only partially correct. The problem solving tools that are taught across the board in Six Sigma training programs are familiar to many who have years of industry and quality control experience. The essential tools that reside in the practice of the methodology and complement its philosophies are statistical process control (SPC), design of experiments (DOE), analysis of variance (ANOVA), the Voice of the Customer, encouragement of creative thinking, and process management. As the training of Six Sigma evolved, along with the certification titles of “Black Belt,” “Green Belt,” and “Champion,” other tools have been added to the list, such as measurement systems analysis (MSA), failure mode and effects analysis (FMEA), root cause analysis, and have been around well before Six Sigma became the new trend. Andell also goes on to say that Six Sigma is very similar to TQM with the only difference really being the major CEO/corporate push and endorsement of personalities like Jack Welch and Larry Bossidy. However, Andell is neglecting several items to make his point. For example, the efficiency of that so-called “repackaging”, which happens to be a variation of the scientific method, better known as the DMAIC model, makes the tools much more timely and effective.

In addition, Six Sigma stresses the complete involvement and cooperation of all levels of management in its effort, via its accompanying infrastructure, which prevents it from becoming a department or sideline activity. The authors of the book The Six Sigma Way take the time to go into depth to address the
question of the difference between Six Sigma and TQM in chapter 3. They recognize that the population of quality professionals that may have been burned by “failed” TQM efforts of the past, will probably be the most resistant to embrace next Six Sigma ventures. They use this chapter to review “some of the major TQM gaffes, as well as hints on how the Six Sigma system can keep them from derailing your effort”[41].

This discussion would not be complete without highlighting the powerful foreword by Neil DeCarlo of Mikel Harry’s poignant book, *Six Sigma Knowledge Design*, which further distinguishes the line between Six Sigma and TQM. In his book *Six Sigma*, Harry has this to say about the difference between TQM:

“The difference between previous total quality approaches and the Six Sigma concept was a matter of focus. Total quality management (TQM) programs focus on improvements in individual operations with unrelated processes. The consequence is that with many quality programs, regardless of how comprehensive they are, it takes many years before all the operations within a given process (a process is a series of activities or steps that create a product or service) are improved. The Six Sigma architects at Motorola focused on making improvements in *all operations within a process*, producing results far more rapidly and effectively” [26].

Neil DeCarlo amplifies the point that Harry makes by stating, “While TQM has devolved into the business of quality, six sigma has evolved into the quality of business” [25]. DeCarlo points out that there is a lack of understanding of how
“six sigma functions as an integrated system for driving business breakthrough,” in that organization need to focus on turning the business around, instead of merely turning a process around. He claims that although management and quality circles are saturated with knowledge concerning Black Belts, the tools, DMAIC and projects, “they are much less educated about the requirements, principles, practices and nuances involved in successfully installing and deploying six sigma…they focus on the details of project application, they tend to overlook tenets of six sigma success” [25].

2.1.7 Section Summary. To summarize, Six Sigma is a philosophy, a methodology, and a process that incorporates change within an organization to bring about improved business results and customer satisfaction. Six Sigma places an emphasis on data-driven, root-cause analysis by using a diverse collection of tools to identify and address the sources of special and common cause variation within the process. The dynamic sequencing of the toolset, business focus and the demand for executive support set Six Sigma apart from the total quality management initiative of the ‘80’s. Because of these and many of other attributes of Six Sigma, it has been the phenomenon credited for the breakthrough success of many of today’s top-performing corporations.

2.2 Analyzing DMAIC

As introduced in the previous section, Six Sigma’s scientific method, DMAIC, is a variation of the Plan-Do-Study (or Check)-Act model developed by Edward Deming. DMAIC, which is pronounced deh-MAY-ikh, is the five-phase
process improvement system that is commonly applied by Six Sigma practitioners and is currently taught in most Black Belt training modules [45].

2.1 The DMAIC Cycle [15]

**DEFINE**
What problem needs to be solved?

**MEASURE**
What is the capability of the process?

**ANALYZE**
When and where do defects occur?

**IMPROVE**
Now can the process capability be Six Sigma? What are the vital few factors?

**CONTROL**
What controls can be put in place to sustain the gain?

DMAIC, or Define-Measure-Analyze-Improve-Control, is sometimes mentioned with three additional steps known as Recognize, Standardize and Integrate, which are exclusively designated for Champions and Master Black Belts to execute. These eight steps are involved in what Mikel Harry and Richard Schroeder refer to as the Breakthrough Strategy in their book Six Sigma. “Each
phase is designed to ensure (1) that companies apply the Breakthrough Strategy in a methodical and disciplined way; (2) that Six Sigma projects are correctly defined and executed; and (3) that the results of the projects are incorporated into running the day-to-day business”[26]. Each phase has a specific purpose and set of desired outcomes that signal the completion of one phase and the beginning of another.

Tools. A few books directly and almost exclusively address tools used to implement Six Sigma. Among those are The Quality Handbook by Joseph Juran and A. Blanton Godfrey, Implementing Six Sigma by Forrest W. Breyfogle III, and The Six Sigma Handbook by Thomas Pyzdek. These books go into each of the tools that are involved in executing Six Sigma. Implementing Six Sigma also goes into other helpful details, such as how to choose the effective training, computer software, Lean Manufacturing, Theory of Constraints, and reliability testing, while The Quality Handbook tends to be a comprehensive encyclopedia of the history of quality, methods, and practical teaching.

Figure 2.2 outlines the tools that are used throughout DMAIC within their associated phases. The tools listed in the chart existed long before Six Sigma began, and have been used long before it became a popular practice. The difference between how these tools were employed before Six Sigma versus after is dynamic sequencing and the integration of these tools in one common line of attack (DMAIC). As a depicted by the chart, many of the tools can be used in more than one phase. In training, they are commonly introduced in the first
phase where they apply. As Six Sigma training has developed, some tools have been associated with certain phases to improve the overall effectiveness of the model.

![Figure 2.2 Chart of DMAIC tools](image)

The tools are a combination of statistically based, graphical, analytical techniques and simple actions that can be assessed as needed by the members of a project team.

Trainers may offer different combinations of this these tools depending on which ones they feel are more important or useful. This thesis will study the tools that are common across six established Six Sigma trainers.
The sections to follow will identify the purpose of each phase of DMAIC and then discuss how the goals of each phase are met using the current toolset. As the purpose of each phase is identified, the tools that are commonly associated with that phase will be briefly described.

2.2.1 Define. A problem solver must consider the area that contains the problem, determine the appropriate focus, and gather all the pertinent information related to the scope that will eventually aid in providing a robust solution. The importance of proper definition is mirrored in the goals of the define phase [33]:

1. Identify and recognize. The first goal of Define is to find opportunities to improve the process, cut costs and/or recognize areas for overall financial reconstruction.

2. Find the business case for the project. The goal that sets Six Sigma apart from other quality programs is the one that mandates practitioners to find projects that have an impact on the bottom-line. This goal involves determining the identity of the customer and why the project is important.

3. Set metrics. In this phase, metrics for project success are set and agreed on by project team members. The metrics are measurable, data-based and driven by customer requirements.

4. Find specifics/narrow scope. Before solving the problem, one must gather facts, initial data, and know the history of the problem. The project team must answer questions such as, “Is the project manageable in the time allotted or the frame of reference given?” Answering such
questions allow adequate description of the “solving space” that contains the problem. Doing so eliminates the wasted time solving the wrong problem or being derailed later.

5. Prioritize. This goal simply addresses project planning and task management. To accomplish this goal a team must consider what milestones are on the horizon and what tasks must be completed in order to reach each milestone.

2.2.1.1 The Tools of Define. The tools commonly linked with Define are the Pareto principle, the process and value stream map, process capability, and the Cause and Effect diagram.

The use of the Pareto principle is exhibited by means of a bar graph chart that shows what processes or causes fit the “80-20” rule, or what twenty percent of the process, people, and equipment, etc. causes eighty percent of problems, waste, or mistakes. This tool quickly narrows the scope of the problem by focusing on the few areas of the process that need to be immediately addressed. The Pareto chart is also used for purpose of problem identification and specification.

Process flowcharting is a graphical method that diagrams the overall process. Although there are different types of flowcharts, most are used to map the route by which raw materials become a finished product [29]. Flowcharts (or process maps) capture the storage, data, decisions and activities that make up the process from start to finish. Process flowcharts map decisions, stages, and documentation that transpire during the process.
Value stream mapping is a powerful tool that constructs a map of the value added and non-value added components of a process flow. It outlines the process from beginning to end, taking into account inventory, paperwork, rework and shipping. Value stream maps and process flowcharts are used for the purposes of problem identification and data management, as an effective means of documentation. After constructing a value stream map, one is able to see bottlenecks that may be present within the process via cycle times and rolled throughput yield. A flowchart may reveal inefficient flow and decision-making.

Process Capability is another tool usually executed in the Define phase. The process capability is determined by calculating the index values for Cp and Cpk. These metrics provide an efficient, universal way of comparing the process to customer specifications. Process capability can be used for “before and after” comparisons so that project teams may have a quantifiable measure of process improvement.

Cause and Effect diagrams, also called Fishbone diagrams, give the project team an opportunity to identify potential causes of process variation. Generally, the possible causes are listed with respect to the six categories of personnel, machines (or equipment), materials, environment, measurement and methods. These possible causes can then be used to “determine the factors to consider within regression analysis or DOE.” [6] This tool helps the users to identify problem areas and view different aspects of the “problem space” by directing their thinking through each of the six areas.
2.2.2 Measure. Before useful data can be collected to gain insight into the process and the problem, the measurement system must be verified. Reasoning behind this phase lies in the fact that gathering data using an unacceptable measurement system will yield inaccurate data and ultimately waste time and resources. Often, simply looking at the process and understanding how parameters are measured will identify improvement opportunities. In this phase, practitioners verify the measurement system by assessing the capability of the system and find the cause(s) for variation of recorded measurements. The goals are as follows [33]:

1. Document existing process.
2. Establish techniques for collecting data.
3. Ensure the measurement system is adequate.
4. Collect data.
5. Establish baseline, including confirmation of financial considerations.
6. Focus the improvement effort by gathering information on the current situation.

2.2.2.1 Tools of Measure. The main tools associated with Measure are Measurement Systems Analysis and Failure Mode and Effects Analysis (FMEA). Process mapping, flowcharts, and performance metrics (process sigma, Cp and Cpk) are also used or redrafted during this phase, as appropriate.

Measurement Systems Analysis or MSA is conducted in two phases. Phase 1 of MSA consists of meeting two objectives. The first objective is to
determine if the “measurement system possesses the required statistical properties or not” (AIAG 1995). The second objective is to determine what effect, if any, do environmental factors have on the system. After determining the acceptability and stability of the system, practitioners verify that the measurement system will continue to produce the initial results in Phase 2. A verified measurement system “is said to be consistent when the results for operators are repeatable and the results between operators are reproducible”[6]. Conducting a statistical study called “Gage R&R” completes this verification. A Gage R&R determines if measurement variation comes from part-to-part variation or from the operator(s).

Failure Mode and Effects Analysis (FMEA) is an analytical technique that seeks to prevent problems by prioritizing potential problems and predetermining their resolutions. The FMEA record is called a “living document” because it requires timely attention and revision in order to maintain its usefulness. There are two types of FMEA: design (d-FMEA) and process (p-FMEA). The P-FMEA is used for DMAIC projects to focus on the potential failure modes, causes and mechanisms that originate from the process. The FMEA is used to direct the analysis effort and is revised throughout the process as information is gathered and causes are verified or dismissed.

2.2.3 Analyze. The purpose of Analyze is to identify the most influential factors within the process and to find the main sources of common cause variation, thereby gaining knowledge of the overall process. Having better knowledge of what influences the process translates to having better control over
the process. It is in this phase that enough data are collected to reduce the variables being considered, find correlation between remaining variables, and began to identify the major sources of variation. The goals of Analyze are the following [33]:

1. Narrow the focus by gathering information on the current situation
2. Uncover potential sources of variation through an understanding of the relationship between X and Y variables
3. Reduce the number of process variables to be acted on in the improvement phase
4. Identify and manage high-risk inputs.

2.2.3.1 Tools of Analyze. The tools used to reach the above goals are the 5 Whys, Pareto and Run Charts, Regression Analysis, ANOVA and other statistical analysis. Again, process mapping, charting and other previously mentioned techniques can be used in this phase as needed.

The 5 Whys is a simple, yet effective tool that is used to bring clarification about process method, procedures, and parameters. It involves asking “Why?” on a particular topic five times in a row while recording answers. By the end of the inquiry, the answers and/or ideas that are uncovered guide practitioners to a list of factors that affect the process.

Pareto and Run charts are used to establish which variables or factors contribute the most to the general process behavior. Run charts are analyzed to
rule out special cause variation and show trends that take place over time. Pareto charts are used in the same way as they are in the Define phase.

Regression analysis is a general tool that involves finding a mathematical relationship between two or more continuous input factors and a continuous output response. Determining such a relationship would enable one to predict process yield given the values of the factors included in the relationship.

ANOVA, or the analysis of variance, is a statistical method for “separating the total observed variability in a measured product property into sources of variation, and for estimating the magnitude of variation that can be attributed to each source” [29]. For example, using ANOVA, a project team can determine if the differences between two or more machines, lines, departments, or procedures is statistically significant. The team can also assess the magnitude of the differences between machines or lines and adjust the process to reduce or eliminate the variation or make sure that best practices are standardized.

2.2.4 Improve. The Improve phase is the most pivotal of the DMAIC model. The purposes of this phase are (1) to develop potential solutions to the identified problems and (2) to optimize the process for the desired yield or performance. “Optimization looks at a large number of variables in order to determine the ‘vital few’ variables that have the greatest impact. Using various analyses, Black Belts determine which variables have the most leverage or exert the most influence”[26]. The goals of this phase are outlined below [33]:

1. To verify the variable relationship
2. To identify, test, and implement potential solutions to address the root cause.
3. To verify the solutions are effective
4. To document the cost benefit
5. To ensure that the solution is robust

2.2.4.1 Tools of Improve. The tools that are used with this phase are brainstorming, design of experiments (DOE), FMEA, and process mapping. Brainstorming is typically associated with creative problem solving. Brainstorming, DMAIC’s tool for solution ideas, can be used informally in project team meetings, but is a very effective tool for generating solution ideas or identifying problem areas if used formally. Brainstorming, a term coined by Alex Osborn, describes a structured process wherein ideas are shared quickly and randomly (like a storm), and then are recorded and built upon. Brainstorming allows ideas to be submitted and modified for providing several viable alternatives to solve a problem or to explore its causes.

Design of experiments is a statistical tool that enables practitioners to gain process knowledge by systematically changing operating levels within a process in order to consider several factors and interactions simultaneously. There are many different kinds of designs depending on the purpose that is intended and the nature of the process being studied. DOE analyses not only report which few factors out of several are significant to the process; it also yields prediction models to optimize the process.
2.2.5 Control. In the Control phase, Black Belts have gained enough information from the previous phases to improve the overall process to hold the gains. This is the part of the process that determines the quality and longevity of the solution: finding ways to live in the solution that has been built. In this phase, practitioners work to [33]:

1. Create and validate monitoring system for the process
2. Develop new standards or revise existing ones
3. Finalize documentation of procedures.

2.2.5.1 Tools of Control. The main tools used in the Control phase are statistical process control (SPC), a technique that utilizes control charts, and poka-yoke (or mistake proofing).

“The most effective statistical process control (SPC) program utilizes the minimum number of charts that at the same time maximizes the usefulness of the charts”[6]. Control charts track processes by plotting variable or attribute process data over time. Poka-yoke, or mistake proofing, is a technique that may use a creative approach to either prevent a mistake or make “a mistake obvious at a glance”[6]. Poka-yoke practitioners may apply a combination of “solution directions” (such as color, physical properties, sound, texture) and random words to a brainstorming session in order to come up with creative ways to prevent mistakes.

2.2.6 Section Summary

Overall, DMAIC makes excellent use and availability of many different types of statistical and analytical tools when the problem solver needs to identify
the problem, collect, and analyze data. However, the DMAIC toolset is considerably wanting in several areas. Below is a list of several observations concerning the content of the Six Sigma toolkit:

- The toolkit is in need when it comes to innovative solution generation. Although brainstorming is both systematic and useful for generating solution ideas, the ideas may not be innovative, robust or easily implemented. Brainstorming has limited capacity if not used in conjunction with another technique, such as solution directions as employed in poka-yoke.

- The available tools do not to address problems that surface as a result of the changes that come about when Six Sigma is being deployed into an organization, such as with infrastructure and organizational culture. Such problems may obscure issues associated with the process or even delay or inhibit solutions to the process problem. Overwhelming differences in personality types and ineffective conventions can limit much needed discussions or discoveries. Although Six Sigma may address these issues in terms of philosophy, there are no tools or systems in place to deal the change that an organization encounters when implementing Six Sigma.

- DMAIC does not have a tool to assist in choosing between alternatives. Innovation requires not only the ability to generate many creative, robust, ideal yet useful solutions, but also the ability
to quickly choose between alternatives and implement chosen solutions as well, especially in the Improve phase.

- Finally, although DMAIC utilizes many tools to yield useful information in each phase, the existing identification tools do not automatically lead the user to a solution. Many of the tools focus users on problem areas only, rather than solution areas.

The next chapter will introduce theories related to problems solving as well as several systematic tools used to accelerate problem solving. Survey of these methods will reveal their ability to complement Six Sigma philosophies and existing tools. These tools were selected for not only their apparent merits but their potential to address the above observations and improve the flow and practice of DMAIC as well.
3.0 Introduction

Popular belief holds that creative ability is limited to a select, gifted few who possess or exhibit this extraordinary, unconventional talent from birth. Though such speculations persist, research efforts conducted in a variety of backgrounds over the last eighty years have pointed toward an entirely different conclusion: creativity can be taught. This idea is often mentioned in the resultant literature and associated circles as “directed creativity”. Those who studied in this area eventually proved that by enlisting certain methods that were systematic by nature and directed the general thinking practice, the process of solving a problem could be accelerated. Continued work in this arena led to the development of several practices and tools known as accelerated problem solving techniques. The techniques are characterized by their promotion of attention-directed thinking, innovation and creativity, and may possess a structured approach.

After citing the efforts of Joseph McPherson, a creativity researcher who collected 28 definitions of creativity, Paul Plsek offered the following in his book *Creativity, Innovation, and Quality*, as a conclusive definition for creativity [43]:

“Creativity is the connecting and rearranging of knowledge—in the minds of people who will allow themselves to think flexibly—to generate new, often surprising ideas that others judge to be useful.”
From this definition, particularly the phrase, “…who will allow themselves to think flexibly…” Plsek suggests, and later plainly states, that creativity is an attribute that people are able to and should cultivate by “purposely mov[ing] out of your comfort zone in many small ways on a regular basis.” By this definition, Plsek logically leads readers towards a definition for creative problem solving; the new, surprising ideas that are generated from thinking flexibly about arbitrary situations are judged to be useful by others. Thus, creativity, for all intents and purposes for this discussion, is synonymous with the term “creative problem solving.”

Innovation is a concept often related to and commonly confused for creativity, or creative problem solving. Innovation is defined by Plsek as “the first, practical, concrete implementation of an idea done in a way that brings broad-based, extrinsic recognition to an individual or organization”[15]. This definition implies that innovation is the direct application of an idea that is not “merely novel, statistically improbable, or bizarre.” Plsek emphasizes the distinction between innovation and creativity by expressing that, “real success comes with innovation.” Thus, it is not enough to be creative; an organization must take the risk to implement the ideas that are generated within its walls.

Seeing that organizational success genuinely comes from innovation, the cultivation of innovation skills by all members of the organization becomes important. However, today’s workforce lacks the skills that would enable them to quickly and effectively innovate. Creativity and innovation are still commonly thought of as random, natural ability given to a “chosen” few. In actuality, these
skills can be developed and honed using systematic tools, tools used to accelerate one’s problem solving ability.

The purpose of this chapter is to present tools designed to accelerate problem solving. The chapter will begin by taking a look at the theories concerning the nature of problem solving. Then, it will draw upon the insight provided by those theories introduced to provide justification for an integrated model, as a preface for the chapters to follow. It will end with the presentation of the accelerated problem solving tools that will be integrated into the DMAIC model, as well as an outline of their compatibility with Six Sigma in philosophy, execution, and purpose.

3.1 Problem Solving Theory.

Problem solving is thought to be a simple concept. Historical research would suggest that many individuals have studied the nature of problem solving and have touched on different aspects in order to facilitate the process. The sections to follow outline some of these findings and in the final section, combine these ideas into one problem solving theory for problems that surface within an organization in pursuit of process improvement.

3.1.1 Problem stages. All problem-solving approaches contain three basic parts (heretofore known as stages). An article by Paul Palady and Nikki Olyai titled “The Status Quo’s Failure in Problem Solving,” illustrates this point. The authors discuss the need for these stages: “Solving chronic problems requires a structured approach beginning 1) with a description of the problem, followed by a 2) detailed investigation of the cause and 3) concluding with the development
and confirmation of the solution” [39]. By choosing to focus on “chronic” problems, the authors suggest the most successful, lasting solutions come from completing some form of these three stages of problem solving.

The first stage involves identifying the problem. No matter how useful a problem solving technique may be, it will be of no use if a project team sets out to solve the wrong problem. Problem identification sets a focal point for solving efforts while setting a perimeter for the solving space that includes the boundary of the problem. Good problem definition will lead to effective research of background information, efficient use of time spent working on the project, and strong metrics used to indicate success.

The second stage involves collecting and organizing data related to the problem’s cause or source. In this stage, collected data are analyzed (organized) to yield as much useful information as possible. Data collection prevents project teams from apply solving efforts to the symptoms of the problem only, ignoring the root cause. Thorough data collection, organization and analysis, or data management, will enable effective and accurate decision making as well as confident project development.

The third and final stage of problem solving is the “solving” itself. Solutions are generated, developed and verified at this point, the best solutions implemented and standardized. If a solution is innovative or robust enough, it will be cost effective, durable, and add little to no complexity to the existing system.

3.1.2 Problem Types. The path of problem solving is often clouded by a mismatch between the solving technique and the problem. In Chapter One, Plsek
revealed that trying to apply the wrong tools to the right problem, i.e. analytical techniques to a creative problem, could inhibit the discovery of solutions. So, before tools can be applied, one must first assess what type of problem is being encountered, be it purely statistical, analytical or innovative. The type of problem will dictate the type of tools that will best solve the problem. Statistical, analytical and innovative (creative) problems are not the same. Each type calls for different kinds of data and asks a different set of questions; which is why they generate different solutions.

Statistical problems are characterized by special and common cause variation in a process. These problems are contained in systems or processes that are given to the collection or interpretation of numerical data, be it discrete or continuous. The questions fall into two main categories: “Does the target need to move?” or “Does the spread need to be tightened?” Statistical problems involve finding the source of inconsistency when the source is not apparent. An example of a statistical problem is inconsistent measurements of bolts taken by three different operators from different shifts using the same type of instrument. The questions of whether or not the operators, shifts, bolts, or instruments are statistically different fall in the category of “(How) Does the spread need to be tightened?”

Analytical problems are probably considered the most common. They are problems that may be complex, begging to be divided into elementary components and solved using basic principles, logic or formulas. These problems request such techniques because the systems or situations containing the
problems may have a logical base, even if the logic or the principle on which the systems are based is not obvious to the solver. Analytical problems involve “thinking through” the issue(s) by asking a variation of the questions “When?” “Where?” “Who?” “What?” and “How?” An example of an analytical problem is determining whether or not the company should pursue a different clientele. The question being asked is “What decision needs to be made?” or “Who should the customer be?” Once this problem is analyzed, the company may find they need to use surveys, other research, statistical tools or even an innovative approach.

Innovative problems tend to be less obvious. They may appear to be analytical or statistical problems at first. However, they eventually defy the solver’s logic or yield conflicting analyses. Innovative problems are characterized by their resistance to “the logical next step” and traditional formulas. These problems require a new approach and a fresh idea, which is may employ an analogy or a hidden principle.

Since the focus of this thesis is to promote innovation by integrating accelerated problem solving techniques into the existing DMAIC model, the implication is that Six Sigma’s toolset already possesses an adequate supply of statistical and analytical techniques. But how does one determine when analytical and statistical techniques are not enough and innovative (or creative) thinking is needed? Because of the difficulty associated with recognizing such problem, Plsek, introduces and outlines the symptoms of “stuck thinking” [43].

“So it is okay to prefer the analytical problem-solving approaches of traditional quality improvement, and it is okay to start with these
methods initially. So when should we consider another approach? When analytical thinking leaves us stuck. We need to be able to check periodically for indication of stuck thinking in our problem-solving and quality improvement efforts. The symptoms are varied, but the checklist [below] will direct your attention. The more items you check off, the more likely it is you and your team are stuck.”

The classic symptoms of stuck thinking are:

- Frustration at being unable to either isolate a cause, propose a solution, or achieve your goals after implementing a solution
- Data collection and analysis efforts that have been going on for a long time, but do not seem to be providing any clear direction
- Reexaminations of data or past thinking that keep coming back to the same conclusions
- Tinkering with failed solution without a clear and compelling theory as to what real difference these minor changes will make
- Accusation that others are simply not being reasonable, logical or cooperative
- Rationalization of the seemingly unreasonable, illogical, or uncooperative behavior of others
- Calls for reconsidering the original goals of the improvement effort because we now realize that these expectations were unreasonable
• Calls for celebrating the achievements of the effort and accepting the new, better—but not as good as we hoped for—status quo

3.1.3 Problem Level. Problem solving can also be confused by the atmosphere where solving is taking place. The problem may start or be evident at the process level, but may extend to or originate from the people or policies surrounding, in control of or affected by the process. Office politics, negative team dynamics and/or constraining policy issues can be lengthen the time to an effective solution for the process problem. Early detection of the level on which the root of the problem actually exist can lead to accelerated problem solving by addressing the overarching issues that may be constraining the application of solving techniques on the process level.

The people who are typically trained to conduct process improvement measures, such as Six Sigma, may not be classically trained to solve problems associated with the personnel dynamics that may accompany a change effort. People, by nature, are not objective or desire change. These realities lead to the problems become evident when project teams are inhibited from progress, have internal disunity or are forced to come to conclusions by time, budget or special interest limitations. An example of a personnel-oriented problem is a team member’s resistance to collect data or implement a solution due to the contrary nature of the politics in his or her department to the project’s goal.

Yet again, the problems within the manufacturing floor may be related to an outdated belief system or organizational tendency that has never been challenged. Lisa J. Scheinkopt, author of the article, “The Theory of Constraints”
describes the concept of paradigm [46]. She describes paradigm as “beliefs or assumptions” that motivate members of an organization to “develop, embrace, or follow” the rules (written or unwritten) without question. For the purposes of this discussion, problems on the paradigm level are those associated with organizational belief or assumptions, i.e. the culture. Process improvement can be thwarted by the widely held belief that the organization cannot afford to invest time, money or energy into an effort or solution. An example of a paradigm-oriented problem is overlooking opportunities to implement solutions to reduce variation and improve the process or profit margins due to belief restrictions despite what data may tell us.

3.1.4 Theory Outline. Considering all of these factors allows the mapping of the solving space to be completed in terms of the stage that the problem is in (definition, data management, solution generation or implementation), the problem type (analytical, statistical, innovative) and the level to which the problem extends (process, personnel, paradigm). Using the combination of these dimensions when approaching a problem will accelerate problem solving by

- Aiding the team make to more efficient use of available tools
- Helping them connect the right tool to the right problem at the right time.
- Enabling them to quickly identify, address and/or circumvent issues that extend beyond the process realm.

Therefore, the following dimensions can classify both problems and problem-solving methods or tools, in order to deliver an efficient match:
• Level: Process-oriented, personnel-oriented, paradigm-oriented
• Type: statistical, analytical, innovative
• Stage: identification, data management, solution generation

Chapter Two revealed that the DMAIC toolkit mainly uses statistical and analytical tools to adequately address process-oriented problems. These tools address the identification and data management stages of the project very well. The solution generation stage is addressed using only one tool: Brainstorming.

3.2 Accelerated Problem Solving Tools.

Mind Mapping, the theory of constraints (TOC), Six Hats Thinking, the theory of inventive problem solving (TRIZ), and Kepner-Tregoe were the tools selected for integration into Six Sigma. Each of these tools is noteworthy for its developed, systematic nature, compatibility with Six Sigma philosophy and goals, and conceptual simplicity. For those reasons, each tends to produce qualitative or quantifiable results quickly and effectively.

Each part of this section will begin with the description of the accelerated problem-solving tool selected for integration as well as the limitations and benefits of each. Each section will conclude with speculation of the tool’s potential usefulness to Six Sigma and a short bulleted summary that will indicate the tool’s classification. If the “tool” is actually a collection of tools (i.e. TRIZ) the section will only outline each component of the collection that will be used in the integrated model.

3.2.1 Brainstorming. Chapter Two revealed that Brainstorming was the only Six Sigma tool that is used for the harvest of fresh ideas. Alex Osborn
developed brainstorming in the 1940’s as a method of allowing creative ideas to spontaneously escape from the sub-conscious [2]. A typical brainstorming session, usually conducted informally, consists of ideas being quickly divulged in random order with no documentation, until an arbitrary number of ideas are compiled. The rapid succession of ideas or the urgency of the problem usually "jars" some degree of psychological inertia to let more creative and useful ideas come forward. Such sessions take place with “think tanks” which are composed of individuals from a variety of backgrounds, viewpoints, and disciplines. They are usually triggered with the statement, “Now, let’s put our heads together!” or the question, “How can we spin this?”

A formal brainstorming session can still maintain a quick pace, although it may be considerably slower than an informal one. Here, the listing of ideas includes documentation of all ideas, with no commentary of an idea’s relevance or merit. The order of submission may still be random, but everyone must receive an equal chance to contribute. Members of a session may pass on their opportunity or alter a previously recorded idea. At the end of the session, the best, most workable ideas are harvested; creating a list of alternatives that may be critically evaluated at a later time.

Osborn developed the concept of manipulative verbs to increase the power of brainstorming [43]. Manipulative verbs are verbs that “suggest manipulating a subject in some way such as changing its size, function, or position. Osborn’s list of verbs is magnify, minify, rearrange, alter, adapt, modify, substitute, reverse and combine.
Brainstorming is a widely known technique that is currently being used as a tool within DMAIC, mostly on an informal basis. Although, effective and more powerful with solution directions, brainstorming is a simple tool used to solve simple problems. G. S. Altshuller studied the developmental history of brainstorming from inception to its evolution into a program called Synectics™. He concluded that the consistently surfacing drawback of brainstorming is that it does not solve complex problems [2]:

“The main merit of these methods of activating the search is their simplicity and accessibility…Methods of activating the search are universal and can be applied for the solution of any tasks—scientific, technical, organizational etc…The principal shortcoming of these methods is their unsuitability for solving rather difficult tasks. The storm (simple or synectic) throws up more ideas than the trial and error method. But this is not much if the “cost” of the task would be 10,000 or 100,000 trials.”

The very aspect that makes brainstorming easy to use and apply is also what contributes to its limitation. If process problems call for ideas that yield more complex solutions, brainstorming may leave a project team on its own, when it comes to the most crucial part of the phase.

3.2.2 Mind Mapping. Mind Mapping is a technique that was reportedly invented and developed by Tony Buzan of the Learning Method Group of England, who felt his technique more closely resembled the natural mechanism of creative, organized thought rather than the traditional “rows and columns” of restrictive linear thought (A full explanation of the technique is explained in The
Mind Map Book by Tony Buzan). Mind Mapping has been described as individual brainstorming, where the session is with oneself. Mind Mapping seeks to “work out” from a problem or idea by constructing a visual map of one associative thought and then “slotting” in new ideas. As one reviews the map,
one attempts to improve on the ideas and connections expressed. Mind Mapping can be effectively done individually or as a group, being easily adapted to use within a brainstorming session.

Similar to brainstorming, mind mapping involves a draft and redraft of ideas. However, mind mapping comes with several distinctions to brainstorming. Mind Mapping is visual, enlisting the use of lines, color, symbols and words to represent data or to make connections. The use of graphics enables the trailing of ideas as the build upon themselves. Because of its visual element, Mind Mapping automatically uses the concept of attention directing or directed thinking. The mapping records a collection of ideas, where no idea is greater than another, just as in brainstorming. And though it does not completely ignore linear thought, the nature of Mind Mapping lends itself to the generation of lateral connections. “Brainstorming attempts to encourage highly divergent ‘lateral’ thinking, whereas mapping, by its structure, provides opportunity for convergent thinking, fitting ideas together, as well as generating new ideas, since it requires all ideas to be connected to the center, and possibly to one another”[9]. The results of brainstorming “usually appear on paper as lists or grids--both unavoidably linear structures: top to bottom, left to right. Mapping is less constrictive--no idea takes precedence arbitrarily” [9]. Below are some advantages of mapping [9]:

- It clearly defines the central idea, by positioning it in the center of the page.
- It allows one to indicate clearly the relative importance of each idea.
- It allows formation of the links among the key ideas more easily.
- It allows one to see all of the basic information on one page.
- As a result of the above, and because each Map will look different, it makes recall and review more efficient.
- It allows one to add in new information without needing to reorganize previous information.
- It makes it easier for one to see information in different ways, from different viewpoints, because it does not lock ideas into specific positions.
- It allows one to see complex relationships among ideas, such as self-perpetuating systems with feedback loops, rather than forcing the fit of non-linear relationships to linear format.
- It allows one to see contradictions, paradoxes, and gaps in the material more easily, and in this way provides a foundation for questioning, which in turn encourages discovery and creativity.

Among the identified uses of mind mapping, note taking for meetings and individual (and possibly small group) brainstorming sessions could be complimentary to the Six Sigma tool kit. Using Mind Mapping throughout the life of the project will give each team member a method for practicing and sharpening his or her creative thinking skills. There are also several companies accessible through the world wide web that provide software that can digitize your mind map, making it dynamic and fluid. These software packages are great for project presentations and explanation of idea/solution generation.
Mind Mapping can be used in Six Sigma to organize data and information on the process and personnel level. During team formation in the Define phase, a mind map can be used to record and explore what each team member can be responsible for, what special skills they can bring to the group, and what their interests are. During team meetings and discussion, all team members, not just the team secretary, can record several ideas, suggestions, and potential investigation areas. (Mind map of meeting notes, NOTE: that no one’s minutes will look the same) This map can be carried away from the meeting, maintain accurate representation of the discussion, while allowing for an individual redraft of ideas. This would bring an essence of continuous creativity and directed thinking throughout the execution of the DMAIC process.

Summary for Mind Mapping:

- Level orientation: **Process, Personnel, Paradigm**
- Problem/Tool Type: Statistical, Analytical, **Innovative**
- Stage: Identification, **Data Management; Solution Generation**

3.2.3 Six Hats Thinking. Edward de Bono invented a method of directed thinking called Six Hats thinking when he penned a book of the same name in the 1980s. De Bono asserts that defense of one's ego is “responsible for most of the practical faults of thinking” [12]. Use of the hats in reference to certain types of thinking can circumvent one's personal attachment to the shared ideas of individual team members during a meeting, discussion, or when an important decision is being made. The six hats refer to six types of thinking that are signified by a different colored hat [12]:

• White – Neutral and objective. Requires information and data that is checked and proven and believed to be true. Looks for missing information.

• Yellow – Optimistic or supportive. Looks for the values and benefits of an idea, pointing out why it will work.

• Green – Growth, possibilities, new ideas. Seeks to be creative and imaginative. Will build off of other ideas to find new ideas.

• Red – Intuitive. Explores feelings, hunches, fears, likes and dislikes. Legitimizes emotions without requiring reasons for the basis.

• Black – Caution. Presentation of negative judgment and expression of why an idea will not work based on logical reasoning.

• Blue – Control. Manages the thinking process, calling for the uses of the other hats. Brings focus, draws conclusions. Moderates.

Besides claiming to increasing thinking effectiveness and being easy to use, Six Hats also claims that it will [12]:

• Move your team from traditional adversarial to co-operative thinking

• Reduce meeting time

• Redress the behavioral factors that impede successful team-work

• Remove the politics from team decisions and meetings

• Provide a common language for the team

• Deliver more effective outcomes – quicker
Six Hats thinking is an effective way of organizing and classifying types of thinking during team meetings while simultaneously preserving individual dignity and fostering team harmony. The use of the hats allows for the referencing of six different types of thinking without labeling an individual who exhibits this type of thought. It also gives individuals the chance to switch stages of thinking quickly by themselves or simultaneously within a group.

Originally, there was consideration involving breaking up the hats and evaluating or using as separate components or tools. However, through further study, it became clear that the hats are truly designed to be and are best used together as one effective tool. For example, if “Bob” is expressing several positive statements about his new idea, another team member can thank him for his yellow hat commentary and then ask him to either put on his green hat to expand his idea, his white hat to test its feasibility or his black hat to test its practicality. This practice is conducted without suggesting that the idea is simple, impractical or far-fetched. It also gives Bob credit for being capable of several other stages of thinking as well as being able to criticize his ideas. This approach also gives other team members a chance to build off of Bob’s idea or provide helpful information to the discussion before it is dismissed or pigeonholed.

One hat to note is the Green Hat. The Green Hat is the only one that brings with it a technique. This technique is called “provocative operation”, or “po”. The word “po” is used to signify when someone is about to make a statement to provoke lateral thinking, another concept that has been defined and developed by Edward de Bono. To put it simply, lateral thinking involves cutting
across patterns of thinking versus following the pattern lines. A po statement is meant to provoke the listeners to change his or her pattern of thinking to another pattern, in order to discover an innovative idea.

Overall this tool would fit well in the Tollgate Reviews at the end of each phase with Champions wearing the blue hat to determine what aspect of thinking is being neglected. It can also be often used during any team meeting as an unobtrusive method by which a moderator can direct the thinking of team to accelerate problem solving or the arrival to a resolution.

Summary for Six Hats

- Level orientation: Process, Personnel, Paradigm
- Problem/Tool Type: Statistical, Analytical, Innovative
- Stage: Identification, Data Management, Solution Generation

3.2.4 Theory of Constraints. The Theory of Constraints (TOC) is a business philosophy that was introduced by the way of its originator Eliyahu Goldratt in his book, The Goal [19]. The “goal” of any business is to increase the rate of throughput by finding and managing constraints within the process. TOC brings the organization’s system from one described in terms of function to terms of “process flow”. This transition enables the focus to shift from the many details to the one or few constraints. Through the use of this theory many organizations have reduced inventory and eliminated bottlenecks. The theory addresses constraints on the physical, policy and paradigm level [46].

Before applying TOC to one’s process, there are two “important prerequisites” that must be completed. They are “1) define the system and its
purpose (goal), and 2) determine how to measure the system’s purpose” [46]. These two steps, which, reworded, are “identify project’s mission” and “set metrics for success” would already be completed by the time an improvement team reached the Measure phase in a Six Sigma project.

3.2.4.1 Physical Constraints. Physical constraints “are those resources that are physically limiting the system from meeting its goals” [46]. Location of a physical constraint simply involves asking the question, “What, if we only had more of it, would allow us to generate more throughput?” Physical constraints come in two types—internal and external. Issues associated with the supplier or problems in the market cause external constraints. Internal constraints are limitations that exist within the process itself. Adjusting certain aspects in the process to alleviate the constraints is done in five focusing steps:

1. Identify the system’s constraint
2. Decide how to exploit the system’s constraint
3. Subordinate everything else due to the above decisions.
4. Elevate the system’s constraint
5. Don’t allow inertia to become the system’s constraint

3.2.4.2 Policy and Paradigm Constraints. There are no systematic techniques to deal specifically with policy or paradigm constraints, but directed thinking in these areas would prove to be very helpful. Policy constraints “are those rules and measures that inhibit the system’s ability to continue to improve, such as through the five focusing steps” [46]. Policies may be written or unwritten and are based on a belief system that has developed in the workplace on the
way business should be executed. These too may need to be subject to change in order to foster continuous improvement.

Paradigm constraints “are those beliefs or assumptions that cause us to develop, embrace, or follow policy constraints” [46]. It is a reality that the way an organization thinks, i.e. the nature of the company culture, can either foster or inhibit improvement and positive change. Recognizing such thinking can release both the mindsets and funds that can foster cost-effective innovation.

Applying TOC in order to find physical constraints would logically fit in the Measure or Analyze phase as an effective way of finding Pareto’s troublesome few. TOC can be used to quickly focus the team’s attention and effort in order to accelerate the improvement. TOC can also be applied to the Control phase to monitor the system and keep it running at its most efficient state, or identify new projects.

Policy and paradigm constraints need to be located during the Define and Measure phases. Locating the organizational thinking patterns that could hinder the success of an improvement effort project definition and removing them could accelerate that success. This would show the commitment of top management, thereby boost team morale and continue to remove other paradigm constraints and alleviate the policy constraints that depend on ineffective beliefs.

Summary for TOC

- Level orientation: **Process, Personnel, Paradigm**
- Problem/Tool Type: Statistical, **Analytical**, Innovative
- Stage: **Identification**, Data Management; **Solution Generation**
3.2.5 Kepner-Tregoe. The problem solving methodology associated with Kepner-Tregoe (K-T) is a “rational model” of decision-making theory [1]. This problem solving strategy was developed by Charles H. Kepner and Benjamin Tregoe to respond to the “critical need for training in problem solving and decision making” [30]. In 1958, they established their business management consulting company, Kepner-Tregoe, Inc. The K-T model was developed through the documentation and study of the “thought patterns of good problem solvers and decision makers” in management, and was later converted into a systematic thinking process model [14].

This model has many benefits. First, because this model seeks to enable rational decision making, it both strongly considers the human element (tempers, opinion, experience, ego) while stressing data-driven analysis. For each stage there are questions to be answered and information to be gathered. The model is simple and can be applied to fairly complex business decisions.

Next, this model holistic, in that considers the past, present and future states of business and faces each state directly. Through the model’s analytical components, an individual or a group is directed to deal with failures, finalize discussions and consider threats and/or opportunities on the horizon.

Another benefit of this model is the fact that it is tailored to both the team and to the individual manager. The model’s version of the critical thinking system that is dedicated to the management team outlines the role that the team should play in each analysis stage. The version for the individual, to paraphrase from a review of the book, *The New Rational Manager*, attempts to break down every
issue into focused, manageable phases, including opportunities to ask quality questions to achieve quality solutions.

The Kepner-Tregoe method (K-T) is made up of four components: Problem Analysis, Decision Analysis, Potential Problem (Opportunity) Analysis and Situation Appraisal.

3.2.5.1 Problem Analysis. In this component, the past is studied to determine the root cause for deviation or failure. The techniques that the creators have associated with this component are divided into the following activities [30]:

- State the Problem (0 techniques) define
- Specify the Problem (2 techniques) measure
- Develop possible causes from knowledge and experience or distinctions and changes (2 techniques) analyze
- Test possible causes (1 technique) analyze/ improve
- Determine the most probable cause (0 techniques) improve
- Verify assumptions, observe, experiment, or try a fix and monitor (0 techniques) improve

These activities may look familiar because they are a description of the first four phases of DMAIC. This section will list and describe techniques (tools), if any, that K-T offer for each activity that do not already exist within the DMAIC toolset.

3.2.5.1.1 Specify the Problem. The two tools that K-T uses in this step actually build upon each other. The first is known as “Specify the IS,” which determines the state of the problem ‘as is’. This is done by specifying details in
four dimensions: WHAT, WHERE, WHEN and EXTENT. Below are the
dimensions, the description of each dimension, as well as the question list per
each:

- **WHAT**—the identity of the deviation to be explained
  - WHAT specific object has the deviation?
  - WHAT is the specific deviation?
- **WHERE**—the location of the deviation
  - WHERE is the object when the deviation is observed
    (geographically)?
  - WHERE is the deviation on the object?
- **WHEN**—The timing of the deviation
  - WHEN was the deviation observed first (date and
time, shift)
  - WHEN since that time has the deviation been
    observed? Any pattern?
  - WHEN, in the object’s history or life cycle, was the
deviation first observed?
- **EXTENT**—the magnitude of the deviation
  - HOW MANY objects have the deviation?
  - WHAT is the size of a single deviation?
  - HOW MANY deviations are on each object?
  - WHAT is the trend?
    - …in the object?
...in the number of occurrences of the deviation?

...in the size of the deviation?

The answer to each question, be it “What IS...?”, “Where IS...?”, “When IS...?”, or “To what extent IS...?” yields a description of the deviation as IS. The second tool, which provides a basis of comparison, asks what the deviation COULD BE but IS NOT, with respect to each dimension. For example, if there are four pipes in system and Pipe 1 is leaking, it would be said that Pipe 1 IS leaking and Pipes 2, 3 and 4 COULD BE but ARE NOT leaking. Completing this step establishes a pattern of analogous thinking through comparing similar objects or aspects within the system. This leads the problem solver to a clearer, more defined picture of the problem.

3.2.5.1.2 Develop Possible Causes. This step seeks to generate a list of possible causes by taking note of any distinctions and by tracking changes made to objects within the system. In the same way that each dimension was addressed before, the user must ask (1) what is distinctive about the comparison of the IS and IS NOT statements and (2) what changed in, on, around, or about this distinction. From this point, the team uses brainstorming to come up with a list of all of the possible causes based on the distinction and changes noted.

3.2.5.1.3 Test Possible Causes. After the list is generated, the user narrows it down by testing each of the possibilities against If-then logic statements to see if the cause can explained by the IS and IS NOT statements created in specification step.
The techniques described above can be used in the Measure and Analyze phases. The techniques build on each other and direct the user's focus to the root cause by looking at the problem through several viewpoints. These techniques are more focused than a simple Cause and Effect diagram. The combination of these methods not only uses logic to draft a set of possible causes; it also tests and eliminates some of the possible causes. This can make Cause and Effect diagram a living project document and much more useful.

Summary for Problem Analysis

- Level orientation: **Process**, Personnel, Paradigm
- Problem/Tool Type: Statistical, **Analytical**, Innovative
- Stage: **Identification, Data Management**; Solution Generation

3.2.5.2 Decision Analysis. This component is used when a choice must be made to avoid unproductive, open-ended discussions and meetings. Kepner and Tregoe noted that many times members of a team might avoid contributing to a decision to avoid controversy or responsibility. “As a result, they may overlook important information, fail to consult the proper people, and make mistakes” [1]. The goal of this tool is to make the process of decision making less biased and therefore, more effective.

Below are the steps involved in Decision Analysis:

- State the decision. This step involves writing a decision statement (much like a problem or mission statement) by answering the questions How? Which? or To what purpose?
• Develop objectives; Classify objectives into MUSTs and WANTs. During this step the team specifies the purposes or aims that should be inherent in the alternative chosen while simultaneously distinguishing requirements (MUSTs) from desires (WANTs).

• Weigh the WANTs. WANTs are then weighted on a scale from 1-10, a weight of 10 being assigned to the most important desire. This is weighting, not ranking; the purpose being to "simply make visible the relationships among the objectives" [1].

• Generate alternatives; Screen alternatives through MUSTs. After a list of alternatives is created, each alternative is considered against the requirements (GO/NO GO). If all requirements are not meet (NO GO), then the alternative is dropped from consideration.

• Compare alternatives against the WANTs. This step is completed by first determining on a scale of 1-10 how well each alternative meets each of the WANTs. A weight of 10 would be assigned to the alternative that best meets the objective. Other weights are assigned relative to the first alternative’s weight (i.e. 10 for “equally meet objective”; 1 for “meets objective a tenth as well”). A weighted score is then generated by first, multiplying the weight of the alternative by the weight of the objective for each WANT, and second, summing up the weighted scores for a total for each alternative.

• Identify adverse consequences. After determining the tentative choice (alternative with highest total weighted score), this step finds the “best
balanced choice” by considering the adverse consequences of implementing that alternative. Completion of this step involves examining each alternative separately when answering at least these following questions in order to find the consequences:

- Where might information about this alternative be invalid?
- What are the implications of misinformation?
- What could go wrong in the short- and long-term, if chosen?
- What could keep this alternative from being successfully implemented?

Then the user rates the consequence of each alternative on the basis of “probability and seriousness”, much like an FMEA. Choosing the alternative that yields the highest potential benefits in light of the most acceptable risks makes the “best balanced” choice. The main limitation of this model is that the decision-making process is highly subjective in that there are no criteria for assessing the weights (1-10) to objectives, risks and alternatives. This makes comparison unclear and potentially ineffective if weighting becomes close, disabling the manager or management team to make a clear-cut decision. However, the model is very complete in and of itself.

DMAIC has no tool to facilitate decision-making, individually or as a group. This tool can fit anywhere but would be make the most impact during the Define and Improve phases.
Summary for Decision Analysis

- Level orientation: Process, **Personnel**, Paradigm
- Problem/Tool Type: Statistical, **Analytical**, Innovative
- Stage: Identification, **Data Management; Solution Generation**

3.5.2.3 Potential Problem and Potential Opportunity Analysis. This component is said to be “the future-oriented thought process” The focus of this stage is to look ahead for “threats and opportunities” and their potential causes. The steps and goals completed in this stage are exactly those of FMEA, the difference being that this stage is intended to be applied to a wider scope (not just the process), anticipate opportunities (not just potential problems), be simpler in application, and involve no scoring or weighting. The steps are:

- State the action—the basic goal or end result of the plan or action to be implemented.
- List potential problems (or opportunities)—future undesirable (or desirable) deviations to be addressed one at a time.
- Consider causes for the potential problem (or opportunity) factors that could create or bring about the anticipated deviation.
- Consider causes for the potential problem (or opportunity)—factors that could create or bring about the anticipated deviation.
• Take actions to address likely causes—ways to prevent the likely causes from creating the problem or ways to encourage the likely causes to create the opportunity.

• Prepare actions to reduce (or enhance) likely effects—ways to minimize the impact of the problem, should it occur, or ways to maximize the impact of the opportunity, should it present itself.

• Set triggers for contingent (or capitalizing) actions—systems that indicate that a potential problem or opportunity has occurred.

No new techniques are offered in this stage, however walking through the steps during the duration of the Control phase could make the experience of that phase feel more systematic and directed.

This technique of directed thinking can be used in the Control phase as in FMEA for items outside of the process or the realm of design, such solutions that involve personnel issues or on the higher level of directing the organization. Other than that, it is not really needed for integration.

Summary for Potential Problem (Opportunity) Analysis:

• Level orientation: Process, Personnel, Paradigm

• Problem/Tool Type: Statistical, Analytical, Innovative

• Stage: Identification, Data Management; Solution Generation

3.2.5.4 Situation Appraisal. In this component, data and opinions are gathered to bring clarity to the situation at hand. This stage should result in
assessed responsibilities, priority setting and action planning, which include
determining what decisions need to be made and how to locate and remove
hindrances to progress. Based on the list of objectives generated during this first
stage, there is a launch into one or more of the previously described stages of
analysis. The steps for this component are:

- List threats and opportunities
- Separate and clarify concerns
- Consider seriousness, urgency and growth
- Determine analysis needed
- Determine help needed.

This would be a very effective directed thinking tool to select potential
projects or during Tollgate Reviews. However, this tool would make much more
impact as the template for bi-weekly reviews conducted by the team leader and
Champion in order to gauge the progress of the project at each phase. This is
similar to the Blue Hat in Six Hat thinking, which considers the discussion to
determine and call for the thinking hat that is needed. In the same way, periodic
analysis of the project is needed to make sure that the team is staying on track,
not losing focus and is receiving the help they need to complete their
improvement efforts.

Summary for Situation Appraisal.

- Level orientation: Process, Personnel, Paradigm
- Problem/Tool Type: Statistical, Analytical, Innovative
- Stage: Identification, Data Management; Solution Generation
3.2.6 Theory of Inventive Problem Solving. TRIZ is the Russian acronym for “the Theory of Inventive Problem Solving”. This theory, which was created by Genrikh Altshuller in the 1940s, has become “a bona fide, scientifically based methodology” [4]. The theory of inventive problem solving is “unique in its ability to help problem solvers generate good solution ideas (all other methods feature the ‘insert miracle here’ moment when it comes to the part of the systematic problem solving process that involves creation of ideas)” [3]. The authors of the book Systematic Innovation suggest that TRIZ, accompanied by Quality Function Deployment (QFD) and Taguchi’s Philosophy of Robust Design will result in customer-driven robust innovation. Even though that may be true, tools under the TRIZ umbrella can stand alone to accelerate innovation and creativity as the need arises. TRIZ’s strong technical and scientific basis lends itself to being a dramatic aide when solving technical problems and contradictions, although TRIZ has also been used successfully in the service side of business.

Through his study of over 40,000 patents, Altshuller made three important discoveries that lead to the foundation of his theory:

1. Problems and solutions are repeated across industries and sciences.

2. Patterns of evolution are repeated across industries and sciences.

3. Innovations used scientific effects outside of the field from which they were developed.
These discoveries led Altshuller to the premise that inventive problems can be abstracted and solved much like math or engineering problems. This concept implies that, similar to mathematics and engineering concepts, “innovation and creative thought in the context of problem solving are supported by an underlying construct and an architecture that can be deployed on an as-needed basis” [46]. In other words, TRIZ arrives to the solution of a problem via analogous abstraction.

Classical TRIZ includes the following tools that will be described in more detail in the following sections:

- Innovative Situation Questionnaire
- The Contradiction Matrix
- Physical and Technical Contradictions
- Systems Thinking and Laws of Systems Evolution
- Su-Field Analysis
- Ideality
3.2.6.1 Innovative Situation Questionnaire (ISQ). The ISQ seeks to methodically gather related information about an innovative problem to aid users in their “understanding of the design system surrounding their problem before embarking upon an improvement process” [46]. The ISQ also gives users “the much need structure to reformulate a problem...into many smaller problems” which provides a much easier flow from problem defining to problem solving [46]. The sections of the questionnaire provide a complete picture by including inquiries about the problem’s environment, history, resources, wastes, desired outcomes and harmful effects.

This tool would bring structure to the Define phase. The ISQ covers the information needed to define the problem from A to Z, and would serve as living documentation of information and a reference as data is added and needed.

Summary for ISQ:
- Level orientation: **Process**, Personnel, Paradigm
- Problem/Tool Type: Statistical, Analytical, **Innovative** (enabler)
- Stage: Identification, **Data Management; Solution Generation**

3.2.6.2 System Approach. The systems approach directs the user to consider the process in which the problem is contained in terms of a network of systems. The approach views the process as the primary system, identifies the super-system and the subsystems of the process, as well as the past, present and future of those systems. The systems approach is a way of reformulating the problem and viewing its components. It uses attention direction to stimulating “wide-angle” thinking to catch details that might have otherwise have been
missed. As a team considers how the technology or process has changed or will change over time, systems thinking will direct them to speculate how the super-systems or subsystems will need to change.

The systems approach is generally used for problem definition and making connections that are usually missed when using traditional thinking. This could easily be applied during Define phase and reviewed during Analyze phase.

Summary for Systems Approach

- Level orientation: Process, Personnel, Paradigm
- Problem/Tool Type: Statistical, Analytical, Innovative
- Stage: Identification, Data Management, Solution Generation

3.2.6.3 Contradiction Analysis. Contradiction analysis contains components, technical and physical contradictions, that are used to resolve a contradiction or conflict, thereby avoiding an engineering compromise. The matrix works in conjunction with the 40 Principles, which are described in the following section. A technical contradiction exists if the improvement of one vital
aspect, or parameter, of a system results in the deterioration of another parameter. Altshuller identified thirty-nine parameters and through his study of patent literature, built a table containing the resolutions of the conflicts of each of these parameters with one another. This table is known as the Contradiction Matrix. The conflicting aspects of a technical contradiction can be generalized to fit two of the 39 Parameters. When the two contradicting parameters are accessed via the matrix, the “world patent base” is opened up to the solver and provides certain principles that can be applied to the problem and lead to an innovative solution.

At times when a technical contradiction resolution does not yield a convenient solution, a physical contradiction maybe formed and resolved. A physical contradiction exists when “some aspect of a product or service must have two opposing states (something must be slippery and rough)” [46]. In order to resolve the contradiction the opposing states are separated from one another using the four Separation Principles, which are:

- Separation in Time
- Separation in Space
- Separation upon Condition
- Separation within a Whole and its Parts.

Contradiction Analysis fits well in both the Analyze and Improve phases. In the Analyze phase, identifying the contradiction within the process would help to not only characterize the process, but also formulate process problems in such
a way that would flow directly into a solution during the Improve phase, where solutions are typically sought.

The 40 Inventive Principles and the Separation Principles provide powerful solution finding tools and directions to bring about innovation and improvement, which can be applied in the Improve phase. The tools used in conjunction with the Contradiction Matrix give users a complete, systematic guide for problem solving for both technical and non-technical issues.

Summary for Contradiction Analysis:

- Level orientation: Process, Personnel, Paradigm
- Problem/Tool Type: Statistical, Analytical, Innovative
- Stage: Identification, Data Management; Solution Generation

3.2.6.4 40 Inventive Principles. The inventive principles that were identified by Altshuller are often used together with the Contradiction Matrix, but “are so powerful that simply looking at the list often stimulates several new ideas,” which justifies listing them as a separate tool [46]. The inventive principles are a list of ideas or proven solution directions that, when used with brainstorming, can yield many innovative ideas. The Principles include, but are not limited to Segmentation, Inversion, Counterweight, Feedback, Composites, Changing Color, Self-Service, Thermal Expansion, Rushing Through, and Periodic Action.

Combined with brainstorming, the 40 Principles yield a harvest of proven solution directions. This fits in the Improve phase as previously mentioned and also in the Control phase to provide ideas for Mistake Proofing. The Principles,
as a tool, are easy to apply and very adaptable to use within process improvement method of DMAIC.

Summary for the 40 Principles:

- Level orientation: **Process**, Personnel, Paradigm
- Problem/Tool Type: Statistical, Analytical, **Innovative**
- Stage: Identification, Data Management; **Solution Generation**

3.6.2.5 Ideality. Ideality is “defined as the sum of a system’s useful functions divided by the sum of its undesired effects. Any form of cost (including all types of waste and pollution) is included in the undesired effects” [46]. Therefore, ideality seeks to increase a system’s useful functions and delights while simultaneously decreasing undesired effects and costs. It follows then that the ideal system is a system that performs the desired effect(s) without itself, existing. Applying the concept of ideality is simply to think of the ideal final result and attempt to adhere to that idea as much as possible. One of the habits mentioned in Steven Covey’s *Seven Habits of Highly Effective People* is to “Begin with the end in mind.” Applying the concept of the ideal final result is doing just that.

There are six paths to improve a system’s ideality. They are:

1. Exclude auxiliary functions.
2. Exclude certain elements.
3. Identify opportunities for self-service.
4. Replace elements, parts, or total system.
5. Change the principle of operation.
6. Utilize resources.

The concept of ideality can have a pivotal influence over idea generation. Often problem solvers will not consider several possibilities because of feasibility concerns. While the ideal or perfection itself may not be attainable, pursuing the ideal situation can yield astounding results. This tool can be introduced in the Define phase to help in setting criteria for the most desired solution as well as be revisited in the Improve and Control phases to the direct the thinking that produces solutions. Ideality can even be applied the Measure phase if need arises for a redesign of the measurement system.

Summary for Ideality:

- Level orientation: Process, Personnel, Paradigm
- Problem/Tool Type: Statistical, Analytical, Innovative
- Stage: Identification, Data Management; Solution Generation

3.2.6.6 Su-Field/TOP Analysis. Substance-Field analysis, or Su-field, is TRIZ’s analytical tool “for modeling problems related to existing technological systems” [46]. A Su-field model is typically made up of three elements: two

![Figure 3.5 Typical Su-field model](image)

\[ S_1 \quad \text{The object.} \]
\[ S_2 \quad \text{The tool.} \]
\[ F \quad (\text{Field}) \quad \text{Energy or force.} \]
substances and a field. The first substance (S1) produces the desired output or function when acted on by the second substance (S2), which is enabled by some type of means or energy field (F). A substance can be any object “of any level of complexity” [46].

In TOP (Tool, Object, Product) modeling, the “Americanized” version of su-field analysis, the substances are called “tool” and “object.” The field, which in su-field can be an “action or means of accomplishing the action”, is called “force” in TOP. In both Su-field and TOP, the field can be mechanical (Me), thermal (Th), chemical (Ch), electrical (E), magnetic (M), or gravitational (G).

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</table>

The object of the useful action

The tool of the useful action

Energy or force, or description of the useful action

A useful product.

Figure 3.6 TOP model and nomenclature

Along with a modeling technique, su-field comes with 76 Standard Solutions to bring the model from an incomplete system, an ineffective complete system, or a harmful complete system to an effective complete one.

Su-Field and TOP Analysis can be applied in the Measure phase as a graphical way to document the system “as is”. The model can then be revised in the Analyze and Improve phases with the Standard Solutions to generate ideas to solve the problem. Su-Field, like most of the TRIZ tools, can be applied to technical and non-technical problems.
Summary Su-Field/TOP Analysis:

- Level orientation: **Process**, Personnel, Paradigm
- Problem/Tool Type: Statistical, **Analytical, Innovative**
- Stage: Identification, **Data Management; Solution Generation**

3.3 Compatibility with Six Sigma.

Each of the tools described above is developed and produces qualitative or quantifiable results. Each system or tool considers one or more of the following in its philosophy:

- the human element (logical, ease of application),
- human tendency for resistance to change,
- synergy and continuous improvement.

These similar or complementary aspects (to those of Six Sigma) lend each method to integration. The tools are also attuned to Six Sigma in other ways, some of which have been identified below:

- Six Hats Thinking and Kepner-Tregoe were designed specifically for the workplace. Each tool has elements that are intended for managing people, which is essential for promoting change. Six Sigma was also designed to be used in the business world. It anticipates human interaction as well as the natural human tendency to resist change.

- In the book *The New Rational Manager*, Kepner and Tregoe define “rational management” as “making full use of the thinking ability of the people in an organization” and states that it “is a continuing process” [1]. Six Sigma also seeks to increase the autonomy and empowerment of motivated
individuals in the workforce, while considering that repeated use of tools and practices will result in continued improvement.

- **TRIZ’s foundational principle of ideality** is similar to Six Sigma’s “perfection is possible” or “pursuit of perfection” philosophy. Whereas the ideal design may not be feasible, directing one’s thinking toward the ideal design allows for both creativity and aggressive innovation. In the same way, an assertive aim toward minimum variation and zero defects results in substantial gains in improvement and cost savings.

- **TOC’s bird’s eye view of the business system** allows the user to take in the process flow versus the separate functions of individual departments. TOC also demands measurable metrics that are driven by the business objectives of the organization, (i.e., the goal of improving the rate of output). This is similar to Six Sigma’s focus on bottom-line results and customer-driven metrics. Among many apparent benefits, TOC is a systematic root-cause analyzer in that it quickly locates bottlenecks and constraints in the process, in policies, and on the paradigm level. This is compatible with Six Sigma’s desire to find the underlying, true root cause of the process problems.

### 3.4 Summary

This chapter began with a look at Plsek’s definitions of creativity and innovation, which led to the discussion surrounding industry’s need for both structured problem solving and innovative thinking. This chapter introduced the
problem-solving theory that derived as a result of study of problem solving methods in general and attempts to compare several different techniques.

The DMAIC method is focused on process-oriented problems using primarily statistical and analytical tools. These tools adequately address the identification and data management stages of problem solving and use only one tool (brainstorming) to address innovative solution generation. Integration of accelerated problem solving tools will enable the Black Belt or project team to address the personnel- and paradigm-oriented problems that are commonly associated with team or change management issues. The accelerated problem solving tools also focus heavily on solution generation and innovative approaches to problem identification and data management. The availability of these tools to the project team will provide aid in the face of "stuck thinking".

The systematic tools that are thought to best promote or enable innovation were introduced as well. There are several techniques and tools that can be integrated to facilitate accelerated, robust problem solving, which is evident by their comparative goals and philosophies with Six Sigma’s. The accelerated problem-solving tools seek to remove the roadblocks that reduce the effectiveness and efficiency of the Six Sigma project.
Chapter Four
The Integrated Model

4.0 Introduction

Although the DMAIC toolkit has many statistical and analytical tools that effectively concentrate on the problem identification and data management stages of process-oriented problems, a typical Black Belt project may encounter issues that exist outside the scope of these tools. These issues may be limitations imposed by personnel, politics or paradigms or come in the form of an innovative problem.

Accelerated problem solving tools can be used to address these issues thereby increasing the effectiveness of the DMAIC practice. Tools from TRIZ, Kepner-Tregoe, Six Hats Thinking, Mind Mapping, and the Theory of Constraints address these issues in a systematic, innovative fashion, while maintaining ease of use and simplicity. This chapter will present the integrated DMAIC model that will enable the project team to address problems on all levels and rapidly generate innovative solutions. This chapter’s layout is similar to that of Chapter Three, in that it progresses phase by phase. Each section will begin with an analysis of the phase in the light of problem-solving theory and the tools already present with the phase. The section will end with an outline of the accelerated problem-solving tools that will be partnered with each phase and a “prediction” of how the tools will improve the dynamic of that stage.
4.1 Overall Integration.

Six Hats and Mind Mapping can be used anywhere at anytime throughout the life of the Six Sigma project. These tools can add many benefits to the team’s practice of the DMAIC process overall. Six Hats can help team members manage meetings, save time and ensure that all aspects of the issue are expressed. Use of this tool separates the type of thinking communicated from the person who is expressing it. It simultaneously allows team members to have a multifaceted outlet and to be capable of more than one type of thinking. Instead of saying that John is being so negative, it can be said that John is wearing his Black Hat. John can be asked to wear his Yellow hat to see what is good about an idea or his Green Hat to produce another idea.

Six Hats is employed to focus team discussions to make meeting time more effective. This is an important benefit considering that Green Belts and many Black Belts work on projects part-time. Six Hats can alleviate the problem of silence in group discussions or one-sided talks or harping on one issue. The moderator (or any group member) can use their Blue Hat thinking to decide what types of thinking are being neglected and need to be expressed. Blue Hat can be used to call for thinking associated with the appropriate phase (i.e. the White Hat for the Define phase, the Green Hat for the Improve phase). This way more well-rounded or more focused discussion can be brought to the table.

The next tool for overall use is Mind Mapping. Mind Mapping maintains the momentum of the thinking process. It graphically organizes ideas or issues that may be brought up during meetings so that lateral expansion can take place
either individually or with a group at a later time. Mind Mapping can help accelerate innovation by encouraging nonlinear brainstorming, which promotes and captures analogous thinking, a proven solution technique.

Mind mapping can also be used during the team formation process to document individual abilities, networking connections, and vested interests. Having such a document can facilitate assignment of tasks and foster realistic team member expectations.

The last tool highlighted for overall integration is Kepner-Tregoe’s Situation Analysis (SA). Six Sigma’s process improvement steps include the Tollgate Review, a periodic meeting dedicated to evaluating projects to ensure they stay on track and focused. Situation Analysis can be used during such a meeting as a template to allow simple, systematic consideration of the team’s progress at any point within the phase. Knowing that the SA will happen periodically (once every 2-3 weeks) can help focus the group. They may wait to express concerns, complaints and ideas during the SA that may not have otherwise been expressed. Combined with Six Hats, SA can yield a very efficient, comprehensive review and road map of the team’s next steps.

Often, an effort is frustrated simply because there are so many tools available and few indicators as to what tool to use. Situation Analysis can be adapted to address this problem and stop a team from getting sidetracked.

4.2 Phase Integration

Accelerated problem-solving tools will be added to each of the phases of the DMAIC process to address problem-solving gaps and increase the efficiency
of the phase. At the end of each section, a grid will show the summary of the discussion with respect to problem solving theory. The integration is shown with respect to the stages of problem identification, data management and solution generation; the types of tools be it analytical, statistical or innovative; and the problem’s orientation level which is indicated by shading: No shading indicates process-orientation; gray shading indicates personnel-orientation; black shading indicates paradigm-orientation. The last page of the chapter is a graphical summary of the placement of accelerated problem solving tools in the DMAIC model.

4.2.1 Define.

Phase and Tool Classification. The active stages of a problem within the Define phase are problem identification and data management. The goals of the Define phase primarily seek to identify the problem. Data collection takes place in this phase, but only to the extent of establishing identity of the problem. Initially, it would appear that the goals of this phase call for largely analytical attention. However, since the problem is being defined and the solution is unknown, one can safely say that the problem type is also unknown. The fact that the problem type may be innovative, statistical or analytical, or even all three, is important to keep in mind.

Figure 4.1 shows the tools associated with the Define phase in terms of the dimensions of problem solving theory. The chart in the figure shows that there are no tools that available above the process level.
The tools of Define are mainly analytical, with the exception of Cp and Cpk, which are statistical in nature. Practitioners generally reach the goals of identifying the problem, narrowing the scope, finding a business case for the project, and setting metrics for success. However, there are no tools taught that identify an innovative problem, if one should arise.

The process in the Define phase needs structure. The tools available do not manage collected data in a way that automatically feeds into the analytical or innovative tools in subsequent phases. These issues can be addressed with the use of the Innovative Situation Questionnaire (ISQ) and the concept of Ideality.

ISQ, or Understanding the Problem (UTP), creates a detailed roadmap of documents and questions that give wider analytical and innovative consideration. UTP, a version of ISQ drafted by Dr. Timothy Clapp, includes the Cause and Effect diagrams for the harmful and useful functions of a system, as well as an opportunity to explore the Systems Approach (See Appendix II). The ISQ also includes opportunities to select decision-making criteria that can be used later.
once solution options have been developed. Once completed, the ISQ can serve as a living document and record of all project information for easy reference and revision. Ideality should be introduced in the Define phase as a way to direct the team’s thinking, starting a process that continues subconsciously throughout the following phases.

By using these tools in the Define phase, the problem is reformulated in a way that will make better use of existing resources, wastes, and historic information. The ISQ creates a methodical inquiry for gathering information about the problem, making the information-gathering portion of this phase more efficient. Mind Mapping is used to aide in the team formation process of this phase by documenting each member’s interests, time commitments and areas of expertise up front. This facilitates the development of responsibilities and the assignment of tasks. Finally, the concept of ideality opens the teams thinking to consider avenues and resources that would have otherwise been ignored; roads that may lead to an inventive, long-lasting solution which may cost less and

![Figure 4.2 Define After Integration](image)
utilize pre-existing resources.

4.2.2 Measure.

Phase and Tool Classification. The goals of Measure appear to activate only in the mode of data management, which includes both collection and organization of the data for the purpose of observation. However, the modes of identification and solution generation may be triggered on a small scale as well. Techniques of data collection may need to be created and implemented if they are not already in place. The demands of the problem are largely analytical and statistical.

FMEA, MSA and particularly Gage R&R are tools that serve largely in a verification capacity, which fall into the problem identification and data management stages. These tools only meet some of the goals of the phase. If there is a need to establish techniques for collecting data or to design a new measurement system, these tools may be limited in their ability to help the project team generate ideas or solutions.

The last goal of the measurement phase desires that information be collected in such a way as to focus the efforts that will ensue during the Improve phase. Of all the tools already mentioned, this goal is met using FMEA, Pareto charts and Cause and Effect diagrams, but only in a limited capacity. In order to focus the efforts that will occur in the Improve phase, the tools used to collect baseline data must translate to the innovative tools being used in the Improve phases.
The identification stage is activated by the need to find areas within the process that most likely contain the problem areas to focus on for the development of the solution. The data management stage is activated by the need to establish the current situation surrounding the problem through data collection and general investigation. Finally, the solution generation stage in this phase maybe activated if the need for an adequate measurement system is not being met. The tools selected to satisfy these needs are the theory of constraints (TOC), Su-field Analysis and Part 4 of the 76 Standard Solutions.

After using MSA to determine if the measurement system is adequate and verifiable, some teams find themselves at an impasse. If the measurement system is not adequate or nonexistent, they are often left own their own to design and implement a new one. Su-field analysis can be used to graphically represent an inadequate measurement system and Part 4 of the 76 Standard Solutions can be used to generate a solution to amend it.
The primary question of TOC can make good use of the thinking associated with the process map constructed in the Define phase. Answering the question, “What, if we had more of it, can increase our throughput?” or “What (area, machine, item, person) drives our process?” will find the constraints on the process and focus the team on the few areas to be studied, rather than the whole process. At that point, Su-Field analysis can be used again to represent the focus areas “as is”, continuing to reformulate the problem in a way that may be beneficial in the Analyze and Improve phases.

Kepner-Tregoe offers a questionnaire for documenting the current situation in the Specify the Problem activity of their Problem Analysis module. Walking through the steps of asking WHAT, WHEN, WHERE and to WHAT EXTENT is a methodical way of conducting and documenting the discussion surrounding the focus area containing the problem.

TOC, Su-Field and the techniques in Specify the Problem are all tools that can bring structure to the Measure phase and enable a more complete attainment of its goals. Su-Field and Specify the Problem are accompanied with documentation methods and logical continuation or counterparts to be conducted in the Analyze and Improve phases. This helps to accelerate the problem solving by providing a record of discussion, ideas and information. It also decreases interruption of the problem-solving process flow from one phase to another.
4.2.3 Analyze.

Phase and Tool Classification. The goals of this phase demand both statistical and analytical techniques to find information, but may need an innovative way to locate the root cause. Since the Analyze phase is typically the phase where the most data are gathered, the problem activates in both identification and data management stages. Solution ideas may readily appear in this phase but should just be recorded and saved for review until the Improve phase (as in the Define and Measure phases).

The 5 Whys, Pareto and Run Charts, and regression analysis meet the goal of finding the factors that have the greatest influence in the process. ANOVA may meet the second goal of explaining the common cause variation within the process. These tools satisfy the demands for identification and data management statistically and analytically, but not creatively or innovatively.
Recalling the point that Plsek made, the solution may be creative rather than analytical. If the team is exhibiting “stuck thinking”, there may be other techniques that can lend more insight to the process and eventually yield a more robust or innovative solution. As the process is studied, failure to look at it holistically or creatively may result in neglecting a wealth of information.

One of the problems that surface in the Analyze phase comes from the abundance of tools available to be concentrated on in the Improve phase. Tools are needed to manage the other tools and quickly draw the project team’s focus to the vital few areas. The tools for this phase include Kepner-Tregoe’s Situation Appraisal, Contradiction Analysis and the continued use of TOC, Specify the Problem, and Su-Field, if appropriate.

K-T Situation Appraisal should be used at this point to manage the tools and to determine the next course of action. For example, primary use of TOC or Specify the Problem in the Measure phase may have yielded several options.
Perhaps a DOE is the next step, or not necessary, and Contradiction analysis can be used given the constraint found in the previous phase. Perhaps, a continuation of the use of TOC, Specify the Problem, and Su-Field would be most beneficial. Whatever the case, Situation Appraisal should be employed when the next step is not obvious to save time, wasted resources and team unity. Situation Appraisal will also yield the opportunity to assess barriers to the data collection or employ a Six Hats discussion. This will increase communication and allow the chance to address issues that are not directly process-related.

These tools give the Analyze phase both dimension and organization. Tools and techniques reach their most efficient use when they complement the purpose of the other tools. Using these tools takes advantage of this sequencing by enabling the process to flow easily from the Measure phase into the Improve phase.
4.2.4 Improve.

Phase and Tool Classification. The goals of this phase may activate all three stages, but largely move away from the identification mode and settles into the data management and solution generation modes. As far as identification, both the central problem and its root cause should have been determined in the previous phases. Thus, the team should be geared up for deriving and developing solution concepts, be sure to document ideas, test and implementation procedures. All three types of tools, statistical, analytical, and innovative, may be needed in this phase.

The tools in this phase adequately serve in an analytical and statistical data management capacity. DOE does foster innovation in the process in that it indicates optimal process settings that may have otherwise been overlooked with the common one-factor-at-a-time experimental practice. However, verifying the variable relationship does not equal creating robust, cost effective solutions. The available tools do not include a creative solution generator, other than brainstorming. Brainstorming alone is a limited tool because the ideas generated remain within the boundaries of the expertise of the members of the project team. Other solution concepts that would bring about innovation may be overlooked or missed simply do due to the lack of exposure to several other areas that may contain the solution concept needed.
Although the development of solutions is the main goal of this phase, Six Sigma practitioners have been without tools specifically designed to enhance their ability to innovate. For this purpose the Contradiction Matrix, Separation Principles, 40 Principles, and the 76 Standard Solutions have been integrated into this phase. Since all of these techniques may prove to create viable, robust solution ideas and alternatives, Kepner-Tregoe’s Decision Analysis has been integrated as an effective, data-driven method to make the best possible decision concerning the implementation of a solution concept.

The Contradiction Matrix, Separation Principles, and the 76 Standard Solutions are the “solving” portions of the Contradiction and Su-Field Analysis. Beginning these analyses in the Analyze phase formulated the problem in a manner that feeds into their accompanying solution generators.

If the previous phases did not need to utilize the tools mentioned in this chapter, directing a team’s thinking with the 40 Inventive Principles and concept of Ideality can still derive innovative solution ideas. Combined with
brainstorming, the use of these proven principles and pursuit of efficiency may yield several innovative solutions without the use of the table or a contradiction formulation.

K-T Decision Analysis includes the essence and purpose of Black and Yellow hats of Six Hats thinking. Decision Analysis considers the good, the bad and the cost of each alternative based on aforementioned criteria (determined in the Define phase with the use of the ISQ). Afterwards, the best possible decision is made. The decision is based on data and agreed upon criteria, considering costs involved and possibilities of field failure.

**Figure 4.8 Improve After Integration**

<table>
<thead>
<tr>
<th>Identification</th>
<th>Data Management</th>
<th>Solution Generation</th>
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<tbody>
<tr>
<td><strong>Analytical</strong></td>
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<tr>
<td>PMEA</td>
<td></td>
<td>Six Hats</td>
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<tr>
<td></td>
<td></td>
<td>Decision Analysis</td>
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<tr>
<td><strong>Statistical</strong></td>
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<tr>
<td>Process Sigma, Cp,Cpk</td>
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<tr>
<td>DCL</td>
<td></td>
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<tr>
<td><strong>Innovative</strong></td>
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</table>

4.2.5 Control.

Phase and Tool Classification. The goals of this phase make demands for some statistical techniques that activate both the data management and identification modes. The goals also indicate a need for innovative tools in the solution generation stage to create a monitoring system or to develop new standards. Generally the demands of the data management stage are satisfied
by using Statistical Process Control (SPC), in that there is a constant collection of information to monitor the process and ensure that it stays within specified control limits.

The tools in this phase address the goals previously mentioned. SPC uses statistics to monitor the process and provide feedback on solution performance. Mistake-proofing uses solution-directions to create potentially innovative ways to prevent mistakes before they are encountered by the customer.

Figure 4.9 Control Before Integration

<table>
<thead>
<tr>
<th>Identification</th>
<th>Data Management</th>
<th>Solution Generation</th>
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<tbody>
<tr>
<td>Analytical</td>
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<td></td>
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<tr>
<td>Statistical</td>
<td></td>
<td>SPC</td>
</tr>
<tr>
<td>Innovative</td>
<td></td>
<td>Poka-yoke</td>
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The second goal, (identifying and documenting methods and processes that ensure sustained gains) can be more aggressively pursued using TOC, the 40 Principles, 76 Standard Solutions and K-T Potential Problem (and Opportunity) Analysis.

TOC can be used to locate the new constraints in the altered process. Now that the improvement(s) has been implemented into the system, the constraint of the old process may have moved. TOC can be used to locate these bottlenecks and proactively deal with them for an even more robust system. TOC
can also be used to recognize belief systems and policies in places that inhibit implementation of control measures.

In the same fashion, K-T Potential Problem (and Opportunity) Analysis can be used look for potential problems that may occur in the new system, be it customer complaints, market shift, or machine malfunction, as well as opportunities for either increased throughput, market, or continued improvement. Since K-T Potential Problem (and Opportunity) Analysis is analogous to a general FMEA (without the scoring), this discussion can be documented using a modified FMEA worksheet, using one worksheet for potential problems and one for potential opportunities.

The 40 Principles and 76 Standard Solutions can be incorporated easily, especially if Su-Field analysis was used in the previous phases. These solution templates can be combined with poka-yoke to accelerate the mistake-proofing for the amended process. Obviously, any tool introduced can be used again

**Figure 4.10 Control After Integration**

<table>
<thead>
<tr>
<th>Identification</th>
<th>Data Management</th>
<th>Solution Generation</th>
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</thead>
<tbody>
<tr>
<td><strong>Analytical</strong></td>
<td></td>
<td>Potential Problem (Opportunity) Analysis</td>
</tr>
<tr>
<td><strong>Statistical</strong></td>
<td>SPC</td>
<td></td>
</tr>
<tr>
<td><strong>Innovative</strong></td>
<td>TOC</td>
<td>Poka-yoke</td>
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</tbody>
</table>

40 Principles
76 Standard Solutions
throughout the project as needed, so the team may make use of Contradiction Analysis and/or Matrix if necessary during this phase as well.

4.3 Summary

Figures 4.11 and 4.12 show the integrated DMAIC/accelerated problem-solving mode in terms of level and stage. This model has considered integration of tools with respect to DMAIC model overall and per phase. The accelerated problem-solving tools help to connect each phase to the previous one, overall improving the process flow of DMAIC. The tools presented in one phase link to its counterpart(s) in other phases. They also improve the documentation of the DMAIC process overall, since most of the tools are accompanied by some form of record keeping or graphical representation. Table 4.1 summarizes how the accelerated problem solving tools fit into the DMAIC model.

<table>
<thead>
<tr>
<th>Table 4.1 APS Tools for DMAIC</th>
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<tbody>
<tr>
<td>TOOL</td>
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<tr>
<td>Contradiction Analysis</td>
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<tr>
<td>Decision Analysis</td>
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<tr>
<td>Ideality</td>
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<tr>
<td>Innovative Situation</td>
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<tr>
<td>Questionnaire</td>
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<tr>
<td>Mind Mapping</td>
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<tr>
<td>Problem(Opportunity)</td>
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<tr>
<td>Analysis</td>
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<tr>
<td>Situation Appraisal</td>
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<tr>
<td>Six Hat Thinking</td>
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<tr>
<td>Specify the Problem</td>
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<tr>
<td>Su-Field/TOP Analysis</td>
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<tr>
<td>Theory of Constraints</td>
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<tr>
<td>76 Standard Solutions</td>
</tr>
<tr>
<td>40 Principles</td>
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Figure 4.11 Integrated Model by Level

<table>
<thead>
<tr>
<th>Define</th>
<th>Measure</th>
<th>Analyze</th>
<th>Improve</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>Personnel</td>
<td>Paradigm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innovative System Questionnaire</td>
<td>Mind Mapping</td>
<td>Ideality</td>
<td></td>
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</tr>
<tr>
<td>Su-Field/TOPS</td>
<td>Six Hats Thinking</td>
<td>Situation Analysis</td>
<td></td>
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</tr>
<tr>
<td>76 Standard Solutions, Section 4</td>
<td>Theory of Constraints</td>
<td>Specify the Problem</td>
<td></td>
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</tr>
<tr>
<td>Contradiction Analysis</td>
<td>Theory of Constraints</td>
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<tr>
<td>Contradiction Analysis/40 Principles, Green Hat (po, random word) 76 Standard Solutions</td>
<td>Mind Mapping</td>
<td>Brainstorming w/ ideality and 40 principles</td>
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<tr>
<td>Problem/Opportunity Analysis</td>
<td>Theory of Constraints</td>
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<td>40 Principles, 76 Standard Solutions</td>
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- **Su-Field/TOPS**
- **76 Standard Solutions, Section 4**
- **Theory of Constraints**
- **Brainstorming w/ ideality and 40 principles**
- **Decision Analysis**
- **Mind Mapping**
- **Six Hats Thinking**
- **Ideality**
- **Situation Analysis**
- **Specifying the Problem**
- **Contradiction Analysis**
- **Brainstorming with ideality and 40 principles**
- **40 Principles, 76 Standard Solutions**
- **Problem/Opportunity Analysis**
- **Theory of Constraints**
- **40 Principles, 76 Standard Solutions**
Figure 4.12 Integrated Model by Stage

<table>
<thead>
<tr>
<th>Problem Identification</th>
<th>Data Management</th>
<th>Solution Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovative System Questionnaire</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specify the Problem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory of Constraints</td>
<td>Su-Field/TOPS</td>
<td>76 Standard Solutions, Section 4</td>
</tr>
<tr>
<td>Situation Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contradiction Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory of Constraints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contradiction Analysis/ 40 Principles, Green Hat (po, random word) 76 Standard Solutions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brainstorming w/ ideality and 40 principles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decision Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problem/Opportunity Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory of Constraints</td>
<td>40 Principles, 76 Standard Solutions</td>
<td></td>
</tr>
</tbody>
</table>
Chapter Five
Case Study

5.0 Introduction

5.0.1 Purpose. The purpose this case study is to report the application the accelerated problem-solving (APS) tools of the integrated model to the first three stages of a Green Belt team project. The case study will 1) present the progress of the team prior to the use of the accelerated problem-solving techniques, 2) highlight the roadblocks to project advancement, and 3) describe the manner in which these obstacles were overcome with the application of the new tools.

5.0.2 Company Profile. The case study was conducted at a nonwovens manufacturing facility specializing in tuft products. The particular plant is a part of the “nonwovens group” of its parent company, which is made up of five divisions: filter, hygiene/medical, interlinings, technical nonwovens, and tuft. The company consists of seventeen production facilities in twelve countries, generating over $780 million in annual revenue. This company’s vision, which is to be innovative and quality-driven in it’s technically demanding applications, is determined by its guiding principles of continuous improvement, leadership, and commitment to anticipate and understand their customer’s needs and expectations.

Seventy percent of the plant’s revenue comes from the nonwovens it produces for the automotive industry. The product is used as first and second carriers for making molded automobile carpet. Such products must maintain stable composition and integrity during installation. The plant also produces inner
carrier layers for rolls and carpet tiles, which makes up the other 30% of their revenue. The lining has to have surface uniformity and high dimensional stability as well. Other products include landscape fabric and filtration materials.

5.1 Background

5.1.1 Project Setting. The plant contains three continuous manufacturing lines, each producing over 26,000 kg of tuft each day. Together the lines represent an evolution of technology, where the second line produces more efficiently and is more technologically advanced than the first. Likewise, the third line is faster and more advanced than the second line. The original project scope was assigned to the second line. However, for reasoning that will be later explained, the focus of the project shifted from the second line to the third continuous line, which will be known as L3.

L3 converts raw polymer to a nonwoven product that is ready to ship to the customer. Figure 5.1 shows a schematic that denotes the general production process of L3. The process begins when supply trucks bring polyester and co-polyester chip to the plant. The trucks fill the silos, which empty into the day tanks. Moisture is removed from the chip in the dryers, and then the polymer chip is melted in the extruder. The spinning process continues with quenching and drawing. The spun polymer is distributed onto a conveyor belt where it is bonded, inspected and set in an oven. Afterwards, a finish is added with a foam applicator. The product is inspected again and then wound onto a roll.
5.1.2 Six Sigma Approach. The project was launched simultaneously with four other projects as a part of a first wave effort to deploy Six Sigma. The plant’s Six Sigma plan involved training 20 Green Belts and assigning them to project teams with the hope of deploying a “critical mass”. The members of each team were from different departments, including finance, quality assurance, maintenance and engineering. The projects were selected and developed by the plant’s manager, continuous improvement manager, and marketing and finance manager. The projects were assigned during the first week of Green Belt training.
The Green Belt training consisted of three two-day sessions, spaced three weeks apart to allow teams to apply the tools taught in class to their projects in the field. The training modules covered the basic Six Sigma philosophies and tools, team training, and guided statistical software exploration. The time concentration for some modules was customized according to the plant's previous exposure and use of certain concepts, such as statistical process control.

5.1.3 Green Belt Team. The team was originally made up five members and then brought to six, when I began to sit in on team meetings. The group was brought back to five during the time the assigned project was being refocused. Table 5.1 shows a chart of how the team changed over time both in composition and in individual responsibility. The “original” team was formed during Green Belt training and functioned without team role assignment for approximately six weeks. The original team met approximately once a month, including training events. The “transition” team existed over time period after I joined, acted as an observer and began to introduce APS tools as needed. As a result, the team began to change focus and function. The significant shift in focus and direction

<table>
<thead>
<tr>
<th>Table 5.1 Project Teams</th>
<th>* Fictitious names</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original Team</strong></td>
<td><strong>Transition Team</strong></td>
</tr>
<tr>
<td>8 weeks</td>
<td>9 weeks</td>
</tr>
<tr>
<td>Harley, Member, Quality</td>
<td>Harley, Team leader, Quality and R&amp;D</td>
</tr>
<tr>
<td>Dale, Member, Maintenance</td>
<td>Dale, Member, Maintenance</td>
</tr>
<tr>
<td>Bob, Member, Maintenance</td>
<td>Bob, Member, Maintenance</td>
</tr>
<tr>
<td>Ace, Member, Line Manager</td>
<td>Ace, Member, Line Manager</td>
</tr>
<tr>
<td>Brad, Member, Finance</td>
<td>Brad, Task manager, Finance</td>
</tr>
<tr>
<td></td>
<td>Elana, Facilitator/Consultant</td>
</tr>
</tbody>
</table>

Beginning with the transition team, the team moved to the structured team. The “structured” team had a central role assignment, and the facilitator had a clearer role and leadership. The structured team met approximately once every two weeks.
was made in the interest of progress and accessibility. The “restructured” team is the team that resulted after the project shift took place, roles had been reassigned and finalized and responsibilities understood.

The team members have been with the plant for 2-5 years in their various capacities. Harley worked as an internal auditor within the plant in the past and is now part of research and development as well as the quality assurance team. Harley’s work focuses on the product development of the non-automotive products that are produced on L3. Bob and Dale work in the engineering and maintenance departments, serving each of the three lines. Ace is the one of the two production supervisors that oversees the operation of all three lines. He is intimately responsible over the second line, although he is very knowledge of the operation of each line. Brad, the finance expert, had valuable knowledge of how quality was captured financially and helped the team to assess a costs savings to the project.

My role on the team involved serving as a facilitator and task manager. Originally, I intended to mainly observe and subtly introduce APS tools as the need arose. Eventually, I was invited to be the team’s Six Sigma coach. I accepted and used APS tools to assist in the completion of project milestones.

The authors of the Six Sigma Way define a Six Sigma Coach as a consultant that provides advice and assistance to Process Owners and improvement teams, “in areas that may range from statistics to change management to process design strategies”[41]. In my role as a Coach, I provided guidance through basic Six Sigma practices, tools and philosophies.
researched and consulted my advisor on questions involving higher complexity as a check for the benefit of the team and the accuracy of the project. My aim as a Coach was to advocate and support their development as problem solvers using the integrated Six Sigma and APS model.

5.1.4 Project Description. The original project focused on determining how standard practice instructions (SPIs) influence the nonwoven fabric properties of products manufactured on the second line. SPIs are lists of the desired process settings needed to produce a product with specified characteristics. These SPIs are unique to the particular product that they are intended to produce. Over time, the fabric properties of product runs, called campaigns, exhibited variation in output values. Although fabric properties were within specification limits, the variation was wide ranging. The restructured project simply applied the same focus to the neighboring line, L3.

5.2 Define

5.2.1 History. Before I joined the team, the team had been working on the project for approximately eight weeks. During the first four weeks, the team identified their input and output data and constructed run charts for Product G100 from historical data. G100 is one of the products with the most stable performance and one of the highest yields.

The input data are made up of two sources: process settings and process data. The process settings, or SPI for G100 includes a list of over 30 process-setting specifications. The process data came in the form of process run sheets, temporary change orders, and the product run closure database. Process run
sheets report the actual process settings in place during the product run. The temporary change orders report a major change in the process settings that may not have been recorded by the run sheet. Changes in the process settings may be implemented per run when the desired properties are not being met. If the settings need to be significantly adjusted on a consistent basis to achieve the preferred outcome, the production supervisor may then change the SPI.

The output data consisted of the physical untufted fabric properties of weight, thickness, tensile load, elongation and trapezoidal tear (shear load). Harley constructed run charts for each property, which are included in Appendix I. Although the scaling on each graph varies, the output for the thickness, tensile load and elongation appeared to shift over time.

Given the project description and initial historical data collection, the team generated and delivered the following problem and mission statements during their second training session:

- **Problem Statement:**
  Subsequent campaigns of material on PA2 do not have the same untufted properties as previous campaigns using identical process set-ups. Approx. 5 hours are spent monthly for the adjustment of process parameters in order to achieve specified product properties on PA2.

- **Mission Statement:**
  The mission of this project is to identify root cause(s) of shifting in the PA2 process and recommend a course of action to improve process set-up
reproducibility. Reducing the average time by 50% to bring product properties into control on PA2 will yield a cost savings of $40,000/year.

The first transition team meeting, which was mainly a question/answer session to gage the progress, allowed team members to equally voice where they felt the project was. At this point the original team felt that the Define phase was complete and the Measure phase was beginning. The variables that affected the process and product quality were thought to be

- The weather: the team believed there to be a summer/winter trend with the property output. They were not able to see a clear trend in run chart data and reported were unable to quantify related information.
- Strange or rare campaigns that “screwed up” other campaigns. In other words, poor planning.
- The supplier: poor or highly variable quality.

5.2.2 Stage Assessment. During the next four weeks, the team had difficulty moving forward. The team was unsure of what items were critical to quality. The team had not identified the customer or developed a team charter. Individual team roles and responsibilities were not clearly defined. Some of the team members were apprehensive concerning the potential effect that the project would have on the process or the quality of the product. I could see that moving on to the Measure phase was a premature step for the team.
During the Define phase, the original team began to experience the following problems:

- Difficulty coordinating schedules or finding time to meet
- Difficulty making progress during and between meetings
- Overwhelmed with data, difficulty finding next step
- Difficulty defining metrics
- Difficulty agreeing project goals
- Difficulty staying motivated and narrowing focus

Many of these problems resulted from the team functioning as a multidisciplinary team, in that experts with different backgrounds were working separately without communication on the same project. The problem with communication was partially resolved with the creation of a team charter. The team charter specified team member roles and meeting times.

As the team met more often, communication increased proportionally. Communicating with the team leader, I sent out meeting agendas beforehand and meeting minutes afterwards so that all stayed aware and informed. Members were able to make changes to the agenda as needed. These actions provided the necessary group structure and helped increase motivation. This transitioned the team into an interdisciplinary team, where efficiency increased due to communication focusing on the same goals.

Since the team had not yet completed certain exercises, such as a team charter, Gantt chart, task list, or the setting of metrics, a recommendation was
made to reopen the Define phase to complete these steps and to tackle some of
the problems mentioned above.

5.2.3 Define with APS Tools. The tools selected for team use during this
phase were Ideality, the Innovative Situation Questionnaire, Six Hats thinking
and Situation Appraisal. I used mind mapping on my own to document the team
dynamics and to record information.

5.2.3.1 Ideality. During the second transition team meeting the concept of
Ideality was introduced. Together the team and I read and reviewed the chapter
on Ideality from the book, Systematic Innovation [51]. Afterwards, the team
members took turns generating simple ideality statements. To mention a couple:

• “The ideal system would be to input the SPI’s and the system will
  output fabric with the targeted properties every time.”

• The ideal system will absorb the variation introduced by the weather
  and the supplier and produce first quality all the time.”

The team briefly brainstormed ways to increase useful effects and decrease
harmful effects. Since the “gap between the current design and the ideal system
should be reduced to zero”, we also discussed what items or aspects of the
process stood in that gap [51]. Some of the following items were identified as
obstacles to ideality are listed below:

• Insufficient understanding of the current process design

• Limited of knowledge of process setting interactions

• Incomplete process run input data

• Lack of chip quality data
The concept of Ideality was very helpful for widening the scope of the team’s thinking and project expectations. Prior to introduction to the tool, the team seemed fairly resolved to the belief that the supplier and the weather was most responsible for the shift in fabric properties and the variation in quality. However, presentation of the concept of ideality enabled the team to consider the possibility of designing a system robust enough to handle changes outside the team’s realm of control. This opportunity allowed me to explain how many of the tools that come with Six Sigma could be used to learn more about the process and find ways to control it. This moved the team focus from uncontrollable factors and speculation to controlling the process and data seeking. This focal shift also opened the team’s consideration of a designed experiment (an avenue that was originally thought to be unnecessary) and increased information sharing.

5.2.3.2 ISQ. Since the team was unsure of how to proceed to closeout the Define phase, I introduced the Innovative Systems Questionnaire, to provide structure and a task list. Understanding the Problem, Dr. Clapp’s version of ISQ, provided a systematic guide that allowed the team to gain a better grasp and deeper understanding of the problem (See Appendix II). During the sessions that were used to fill out the ISQ, the team expressed assertions that their previous view of the project may have been narrow. Having to answer the questions in the ISQ caused them to “take a step back and reconsider their conclusions.”

The ISQ also presented itself as a useful document that was frequently used as a reference. Many of the documents that were developed by completing the ISQ were made assessable through the electronic document via hyperlinks.
Using the ISQ, we completed many of the steps needed to close the Define phase, including drafting the Gantt chart, outlining Cause and Effect diagrams, setting metrics and creating an accurate process flow chart. The ISQ facilitated a systematic gathering of information and provided an opportunity to more thoroughly explore problems and issues attached to the project scope.

5.2.3.3 Six Hats Thinking. Before closing the Define phase, I used two techniques to conduct the team’s Tollgate Review. Six Hats thinking was used to resolve the lack of information sharing that became evident in the team. Instead of using the hats, I wrote the purposes of five of the hats on one page of the flip chart, i.e. data/information, intuition, positive perspective, new ideas, and cautious perspective. We used this exercise to explore the team’s take on its progress and bring any suppressed issues out into the open.

This discussion was pivotal. Allowing team members to express their intuition (red hat) brought out how political issues were affecting the team’s ability/desire to collect data or conduct a designed experiment. The team expressed reasons for being unmotivated and commented on the progress of the other project teams. This helped to build morale and team solidarity, as everyone began to understand why assigned tasks were not being completed.

After intuition was expressed I asked the team to share any new ideas (green hat). Ace, the production supervisor suggested that the project should shift from the second line to L3. The team expressed their positive perspectives (yellow hat) on this idea. Among those were more control and association over the line, decreased political tension and more latitude for designed experiments.
After considering the facts (white hat) and the concerns (black hat) associated with the idea, the team decided to consider moving the project from L2 to L3.

5.2.3.4 Situation Appraisal. Next, I guided the team through a Situation Appraisal so the team could systematically consider the new situation and decide on the next steps to take. The results are depicted in Figure 5.2 below:

Figure 5.2 Situation Appraisal for Define
As a result of the discussion, the team agreed to prepare a designed experiment and to seek further guidance and support from the plant’s leadership. The revised problem and mission statement became:

- **Revised Problem Statement:**
  Subsequent campaigns of material on L3 do not have the same untufted properties as previous campaigns using identical process set-ups. Approx. 5 hours is spent monthly for the adjustment of process parameters in order to achieve specified product properties on L3. The cause of this variation is unknown and prevents us from entering other markets that require us to adhere to tighter specifications.

- **Revised Mission Statement:**
  To identify root cause(s) of shifting in the L3 process and recommend a course of action to control or minimize them. To reduce variation in fabric properties 10-15% on products manufactured on L3 will yield a cost savings of $60,000+/year by the end of the year.

5.2.3.5 Mind Mapping. By the end of Define phase and with the use of the new tools, I was able to construct a mind map of the team. This helped me keep track of the team dynamics and later became useful to the team as a whole in the following phase. I was able to continually add to the mind map as more information about the interests and abilities of each member came forward. A sanitized version of the Team Dynamic Mind Map is contained in Appendix II.
5.3 Measure

5.3.1 Measurement System. The change in the project scope from L2 to L3 increased the level of the team’s autonomy over data collection and monitoring. During this phase the team identified which aspects of the system they were able to measure, which they were not certain of, and which aspects they would be able to measure soon. We found that most process settings could be controlled to fractions of a unit, monitored and verified. The document that contained verification of the process settings was called a run sheet and was printed out after each campaign. The lab where fabric properties are measured, undergoes a full MSA (including a Gage R&R) a four times a year to maintain ISO 9000 certification.

5.3.2 Process Sigma and Capability. While waiting for preventative maintenance to be administered to the line, the team defined what defect, defect opportunity, and unit meant in terms of L3. The team decided to quantify the product on a basis of weight in kilograms. The measure was described as number kilograms of product that passed the highest inspection, as known as “first quality”. A defect would be anything that is not first quality and would be measured by subtracting first quality from the total amount of raw material that was input into the system. Opportunities, or defect opportunities, fall into the following categories: cosmetic defects, failure to meet fabric property specifications, all wastes, and returned product.
The output performance measures were:

<table>
<thead>
<tr>
<th>Process Yield</th>
<th>Process Sigma</th>
<th>Defects per Million Opp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>74%</td>
<td>2.1</td>
<td>277,000</td>
</tr>
</tbody>
</table>

Process capability was more difficult to determine. The usual company practice was to provide the specification limits of the fabric properties to the customer. Assuming the customer did not know what they wanted, they were offered several product samples and choose from the submission after testing it in their own process. If specifications were wide enough, the product rarely fell out of the set limits.

5.3.3 Data collection. The team chose which fabrics to monitor and to conduct the designed experiment. Harley, who possessed the most knowledge of the products made on L3, collected the descriptions and SPIs for six products. The team chose Product H100. Product H100 is very similar to the G100 that runs on L2. Like G100, H100 has similar property targets and process settings. However, G100 has tighter specification limits than H100 and is usually sold to automotive customers, whereas H100 is sold to ‘tuft other’ customers.

5.3.4 Stage Assessment. As the Measure phase progressed and the team collected baseline data, team became discouraged by the line’s extensive detail, complexity, and history of changes. The team also exhibited signs of “stuck thinking”, specifically:
• **Frustration at being unable to either isolate a cause, propose a solution, or achieve your goals after implementing a solution.** Although it was too early to assess the root cause, the team was frustrated with feeling as though they were far from knowing the cause(s) of the variation due to the complexity of the process.

• **Data collection and analysis efforts that have been going on for a long time, but do not seem to be providing any clear direction.** At this point the team had been collecting process data for nearly three months.

• **Rationalization of the seemingly unreasonable, illogical, or uncooperative behavior of others.** The team members expressed discontent with some barriers to the improvement process, but then began to resign to accepting the roadblocks due to frustration.

• **Calls for reconsidering the original goals of the improvement effort because we now realize that these expectations were unreasonable.** The team began to wonder if the mission was too aggressive or too much for Green Belts to do part-time.

The team exhibited four of eight symptoms of stuck thinking, a clear indication for the need for opportunity to think differently [40].

5.3.5 Measure with APS Tools. To help the team think about the project differently, I presented the Theory of Constraints and Specify the Problem. Use of these tools resulted in a breakthrough in thinking as indicated by a reduction of symptoms.
5.3.5.1 Theory of Constraints, process level. To help narrow the focus of the project work, I used TOC to identify what part of the process was most critical. Often when I would ask the group to identify the most critical part of the process, the response was, “It’s all critical.” The team was concerned about selecting a part of the process to focus data collection on simply based on experience or opinion; however they were equally as hesitant to start strategizing ways to collect data to verify the Pareto principle.

I selected TOC to locate the focal point. To apply the concept, I asked the team the following questions as they viewed a detailed schematic of L3.

- What, if we had more of it, would increase our throughput?
  - Answer: Better quality!

- Where in the line is quality of the fabric most determined?
  - Answer: Uh, the…spinning process.

- Okay, where is the system constrained?
  - Answer: (frowned expression)

- Which part of the line pulls the polymer through the system?
  - Answer: The pumps. The Oven. The conveyor.

- Beginning from the end of the line, which piece of equipment could I turn off (with the rest of the system functioning) and not find myself standing in a pile of polymer?
  - Answer: The spinning process. The spinning process pulls the polymer through the line.
The end of this discussion confidently centered the team’s focus on the spinning part of the process, particularly the areas between the drawing chambers and the oven. After this exercise the team was more motivated to collect data and study the spinning process.

5.3.5.2 Theory of Constraints, paradigm level. As mentioned earlier, the team had trouble determining capability of the process. As I engaged in a dynamic discussion with one of the team members I used the 5 Whys tool to determine why process capability could not be measured using customer-set specification limits. The discussion revealed the presence of three constraining paradigms: (1) the customer does not know what they want...we have to tell them; (2) asking the customer what they want will tip them off to problems with the process and result in lost revenue; and (3) some customers are elevated over others. Acting according to this belief prevented the team from surveying customers or realizing the urgency of consistent customer complaints. After breaking this paradigm constraint, the team member found data on reported complaints. The specification limits for the process capability study were then set to the tightest set of specifications.

5.3.5.2 Specify the Problem. Specify the Problem (STP) was used to focus on the fabric properties and gain more understanding of the system “as is”. The results of the execution of this exercise are shown in Table 5.3. The team participated in rigorous discussion of the purpose of the project, the history of the problem(s) and how to measure improvement, defects and performance.
Table 5.3 Specify the Problem

<table>
<thead>
<tr>
<th>Question</th>
<th>IS</th>
<th>Could be but IS NOT</th>
<th>Distinction</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHAT specific object has the deviation?</td>
<td>Fabric Properties for H100</td>
<td>Fabric Properties on G100</td>
<td>G100: automotive customer</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Different lines</td>
</tr>
<tr>
<td>WHAT is the specific deviation?</td>
<td>Low thickness</td>
<td>Low weight</td>
<td>Thickness is more complex than weight</td>
</tr>
<tr>
<td>WHERE is the object when the deviation is observed?</td>
<td>QA Testing Lab</td>
<td>Online QA System</td>
<td>Online system on Lab</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>for constant calibration</td>
</tr>
<tr>
<td>WHEN was the deviation observed first?</td>
<td>After L2 switch to Steel Roll</td>
<td>During L2 Cotton Roll production</td>
<td>Cylinder Pressure change; Cotton vs. Steel</td>
</tr>
<tr>
<td>WHEN since that time has the deviation been observed? Any patterned?</td>
<td>Continuous Problem</td>
<td>Runs consistently after tweaking, (during long</td>
<td>Time to thoroughly adjust the process setup</td>
</tr>
<tr>
<td>HOW MANY objects have the deviation?</td>
<td>All six “tuft other” products selected</td>
<td>campaign runs)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G100 series</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHAT is the size of a single deviation?</td>
<td>Avg. deviation = +/- 5% to -20%</td>
<td>+5%</td>
<td>Heavier material maybe more forgiving</td>
</tr>
<tr>
<td>WHAT is the trend in the object?</td>
<td>Thickness is usually under target</td>
<td>Above target</td>
<td>N/A</td>
</tr>
<tr>
<td>WHAT is the trend in the number of occurrences of the deviation?</td>
<td>About 50%</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The following points surfaced as the discussion ensued:

- Thickness is a complex property, in that several factors may influence its consistency.
- The online quality assurance system is dependant on the quality assurance lab. This means that it may take up to four hours to secure data for calibration. The system must be calibrated for each SPI or campaign change.
- Heavier material may be more “forgiving” and easier to optimize than lighter materials.
The discussion revealed an underlying problem the team was having during many of the discussions having to do the project’s direction. The team had two goals: process improvement and product development. Both goals relied on a better understanding of the process. However, the difficulty encountered while trying to find common answers to the STP questions, revealed that we could not pursue both goals simultaneously. (I had captured this concern on the Mind Map of Team Dynamics earlier during Define. This helped identify the source of strained discussion during the execution of the STP exercise. Afterwards, the exercise went more smoothly.) Through the use of this tool, the problem at hand became much clearer and the team’s goal more understood and unified. This brought the team to a transdisciplinary level, where the team communicated over a common goal and functioned together as one unit.

5.4 Analyze

Using much of the discussions and information uncovered in the previous phases, the team as a whole was confident about the need for and pursuit of a designed experiment. The theory of constraints drew our focus to the spinning portion of the line, which allowed us to narrow the list of factors for the design.

I directed the team’s thinking by using a simple “reverse progression” technique to locate the “vital few” factors. I asked the team, “Which process settings are related to a specific fabric property?” The fabric properties that we were focused on were weight, thickness, tensile stress and elongation. The result of the discussion is as are listed in Table 5.4.
Table 5.4 Fabric Properties and Associated Process Settings

<table>
<thead>
<tr>
<th>Property</th>
<th>Associated Process Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>Spin pump speed, Calendar speed (and conveyor speed), side baffle setting</td>
</tr>
<tr>
<td>Thickness</td>
<td>Calendar pressure and temperature, Secondary air volume and temperature, Polymer viscosity, Tertiary Air Pressure</td>
</tr>
<tr>
<td>Tensile Load (and elongation)</td>
<td>ATD temperature, Calendar pressure and temperature, Secondary air volume and temperature, Polymer viscosity</td>
</tr>
<tr>
<td>Trap Tear</td>
<td>ATD temperature, Secondary air temperature, Calendar pressure</td>
</tr>
</tbody>
</table>

Harley gathered process data for the fabric properties of G100 and created run charts for each of the properties over time (see Appendix I). The charts revealed that although weight and trap tear tended to be consistent over time, thickness, tensile load and elongation tend to shift down over time. Given Table 5.4, customer feedback and the run chart data gathered, the team identified the following as y’s and critical x’s:

\[
\text{Thickness, Trap tear} = f(\text{ATD temperature, Secondary Air Temperature, Calendar Pressure, Tertiary Air Pressure})
\]

5.5 Improve

5.5.1 Initial Design. The team decided to move forward with planning a designed experiment. Since the team wanted to explore the process, we selected a \(2^k\) design with eleven factors. A resolution of IV would yield 32 runs, allowing us to clearly study main effects and two-factor interactions. As we began to discuss the logistics of a designed experiment several important points came to light:
• The process is continuous and equilibration is a limiting factor; therefore complete randomization may not be possible.

• Off quality product must be minimized. Therefore the levels of each factor selected must stay within tolerance limits.

• The DOE must be run during the normal operation of the line.

• The cost of having the line down is $2000 per hour, not including raw material.

• Through experience, the team was aware of the most influential factors, but is uncertain of the quantifiable extent of their influence as well as their potential interactions.

5.5.2 Initial Data Collection Plan. The team estimated that it would take 1.5 hours to run one cycle of the DOE, which includes changing settings and giving the system time to equilibrate. With the team members taking shifts to monitor the experiment and data collection, the team felt it best to do the DOE in one continuous run, if possible. The hope was to collect as many samples as possible and gather the lab test data simultaneously to avoid periods of inactivity and loss of data or control over collection.

The team decided the sample size must be on a full roll. The material would be tagged as it is gathered onto the master roll. After the DOE is completed the material would be divided in sample rolls and coordinated with the runs of the DOE.
5.5.3 The Final Design. With further discussion, the team decided that it was not necessary to explore what factors were important; since they were confident through years of practical experience which factors were associated with certain fabric properties. Instead, they wanted to quantify the influence of the main factors and learn more about the effects of the interactions. Because of these refined goals and the aforementioned process restrictions, the recommendation made was to pursue an Evolutionary Operation (EVOP) procedure to monitor and improve the process. EVOP designs are ideal for continuous processes that must run with specification limits. EVOP involves making incremental changes of two to three variables in order to find a “signal” in the process “noise” on a daily basis. Therefore, the intent is for the method to be “applied by plant personnel themselves as a continuing normal part of process operation”[5]. This aim would be executed since the team has direct daily access to the line. Though data collection may take much longer than previously anticipated, the goals of producing no off quality and finding the preferred settings will be met. The team will still be able to calculate the main effects and two-factor interactions “as well as a ‘change in mean’ effect at the conclusion of each cycle”[4].

The team wanted to monitor three factors and chose thickness as the most critical property. The factors will be Calendar Pressure, Secondary Air temperature and Tertiary Air pressure. Normally, the three factor EVOP design will “make powerful use of the $2^3$ factorial design”, which has eight runs per cycle. However the introduction of a centerpoints and blocking, the team will be able to
arrange the runs so that day-to-day, batch, or shift differences will not affect “the comparisons of principle interests” [4]. This modified design, depicted in Figure 5.3, will be run in two blocks per cycle. The five experiments in Block I are indicated by filled dots; the five experiments in Block II designated by open dots with the center point being run in both blocks [4]. This modification results in ten runs per cycle. The cycles are run repeatedly until a change in the process is noted. When a change occurs it is said that a phase has been completed [5].

5.5.4 New Data Collection Plan. The team will keep track of run data with a virtual Information Board that will be accessible to the team members throughout the life of the EVOP. Harley and Ace will act as operation supervisors and occasionally trade off to Bob and Dale, if necessary. The team will monitor the other fabric properties as they study changes in thickness. The team will be able to collect two thickness data points per run and, depending on process planning, may be able to execute 10+ runs per week.

Among the many benefits of using the EVOP method is that variations on the design can be used to optimize the thickness or another property, follow the drift in the process and control product quality.
5.6 Summary and Lessons Learned.

5.6.1 Summary. Accelerated problem-solving techniques were applied mainly in the Define and Measure phases. However, the effects were evident in the Analyze and Improve phase as well. Figure 5.4 highlights the tools used during the case study in white. Below are the conclusions of how the tools impacted the DMAIC process by phase and overall.

Overall. The APS helped the team to overcome hindrances that prevented the practice of original DMAIC toolkit, by addressing problems that resided on the personnel and paradigm levels. The benefits of these tools included increasing effective communication during meetings and individual conversations, decreasing circular conversations, reasoning and conclusions and uncovering, improving and tracking team dynamics. Use of the APS tools allowed all team
Figure 5.4 Integrated Model For Case Study

<table>
<thead>
<tr>
<th>Problem Identification</th>
<th>Data Management</th>
<th>Solution Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Innovative System Questionnaire</td>
<td></td>
<td>Ideality</td>
</tr>
<tr>
<td>Mind Mapping</td>
<td></td>
<td>Situation Analysis</td>
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<tr>
<td>Six Hats Thinking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theory of Constraints</td>
<td>Su-Field/TOPS</td>
<td>76 Standard Solutions, Section 4</td>
</tr>
<tr>
<td>Specify the Problem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contradiction Analysis</td>
<td>Theory of Constraints</td>
<td></td>
</tr>
<tr>
<td>Mind Mapping</td>
<td></td>
<td>Contradiction Analysis/40 Principles, Green Hat (po, random word)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Brainstorming w/ ideality and 40 principles</td>
</tr>
<tr>
<td>Problem/Opportunity Analysis</td>
<td>Theory of Constraints</td>
<td>40 Principles, 76 Standard Solutions</td>
</tr>
</tbody>
</table>

Six Hats Thinking

Mind Mapping

Contradiction Analysis

Brainstorming w/ ideality and 40 principles

Decision Analysis

Theory of Constraints

40 Principles, 76 Standard Solutions
members the opportunity to improve thinking abilities. The positive effects carried over from phase to phase.

The tools were not hard to grasp and took a relatively short time to present and apply, once the method of presentation was established. Knowing the symptoms of stuck thinking indicated a need for the tools, so that application was effective and the introduction of APS tools was welcomed. Overall, the team reported a positive reaction to the tools, the learning experience and the results.

Because the philosophies of the APS tools are complementary to those of Six Sigma, tool application often yields opportunities to reinforce Six Sigma themes and project “buy in”. APS tools were used in conjunction with the original toolkit and promote the use of the original tools.

Define. The APS tools brought structure to the phase and challenged the team to gain more knowledge of the process and the problem. The tools also caused team members to reconsider preconceived notions of the root-cause and the solution.

Measure. The APS tools provided conceptual breakthroughs in this phase. The tools helped to quickly narrow the focus when traditional methods could not be efficiently executed. The systematic, logical nature of the tools enabled confidence in the outcomes and decisions made as a result of application exercises.

Analyze. Because of the rigor of three first two phases, the team as a whole retained use of the APS tools and began to apply certain concepts at will,
such as the Ideal Final Result. The Analyze phase was accelerated (2 weeks) in comparison to the length of time of the whole project (16 weeks).

Improve. By this time the team’s confidence and morale had increased dramatically when compared with the start of the Define phase. Because of the use of the APS in Define and Measure, the team’s thinking opened to the possibility of controlling a process thought to be out of reach. Plans are now in place to conduct an EVOP. The APS tools opened a door for more advanced DMAIC tools by removing self-imposed limitations.

5.6.2 Lessons Learned. The lessons learned from the construction and execution of this integrated model in a practical setting are summarized below:

- Team roles, especially a consultant’s role, should be clearly assigned from the outset to avoid later conflict or resentment.

- The best way to present the APS tools while coaching was to first, announce what I was about to do. For example, I would say, “The battery of questions that I am about to ask will lead you somewhere. Stay with me.” Then I would apply the tool, taking the team’s mental focus with me. After a breakthrough in thinking occurred, I went back and explained the tool I used and its principles. This learn-by-doing approach is used with military training and was very effective in this case.

- Identifying and resolving differences in team goals early on can help accelerate project movement. Duality of goals leads to phase recycling and confusion. APS tools facilitate the type of discussions that can quickly
bring this kind of information to the surface relatively quickly (approximately 30 minutes).

- Unresolved Personnel- and paradigm-oriented issues inhibited the team’s ability to focus on the actual process-oriented issues. APS tools can be used to identify these issues while circumventing office politics and preserving the team and the individual’s well-being.

- Issues related to Six Sigma infrastructure being in place can be affected with the use a Six Sigma Coach, consistent meetings and the APS tools to keep a project on track.

- Allowing members time during to complete tasks was very effective. These were called “working meetings” and occurred about once every three weeks. Since Green Belts are defined as part-time Six Sigma practitioners, this meeting was helpful and well-received by the members.

- Past failed quality program attempts need to be discussed before starting a project. The use of Ideality can open a discussion of why and how Six Sigma differs from other programs. Focus on the past takes away from the team’s energy and focus on the present.

- Personal Note: My thinking changed dramatically. I found that I had more confidence to attempt to help solve problems. I approached each problem with the belief that there is a solution. I brought this attitude with me to the team meetings. I encouraged them to believe that, not matter how overwhelming the problem may be, perfection is still possible.
6.0 Introduction.

This thesis presented a model in which accelerated problem solving tools were integrated into the preexisting Six Sigma scientific method for process improvement, DMAIC. The thesis included a case study that reported the outcome of applying the integrated model to the proceedings of a Green Belt team project, just after that team had completed training.

The integration of the accelerated problem solving tools into Six Sigma brought many benefits. Six Sigma’s tools are designed to treat problems that occur on the process level. These tools are traditionally analytical or statistical in nature and do not necessarily direct the problem solver to think differently or creatively. The incorporation of the accelerated problem-solving tools adds techniques to the toolkit that operate on problems that exist at the personnel and paradigm levels. The problem solving tools also promote innovative thought and accelerate problem solving.

The indication of the benefits came not only from the expressed comments of the team, but also from lower number of “stuck thinking” symptoms, increased communication, and increased unified team activity.

6.1 Justification of an Integrated Model.

One might say, “Problem solving tools are well and good, but do we really need such tools to be added to Six Sigma?” One may casually refer to dealing
with personnel-oriented problems and the paradigms that hinder their ability to solve process problems as “tinkering with soft skills” [58]. Janet Young of American Express would reply, “The human variable is not the soft side; it’s the hard reality of influencing and motivating employees to drive performance change”[58]. When 80% of project initiatives fail because of neglecting the human side of organizational change, the best bet is to employ tools that deal with the problems that may occur rather than to just simply hope for the best [58].

An integrated model is justifiable for three reasons: (1) Six Sigma toolkit needs to be versatile to handle several different types of problems, not just statistical process problems; (2) stuck thinking; and (3) personnel- and paradigm-oriented problems can act as a barrier to process improvement efforts.

6.1.1 Reason One: Versatility. Seeing that one project may have many aspects, all of which may need to be addressed, it follows that there are techniques (or a need for techniques) that specifically address each aspect. Many so-called “problem solving” techniques do not actually solve the problem; rather they contribute to solving the problem by identifying it or by collecting and organizing data associated with it. Different techniques may address the same problem at different stages, levels, or degrees. Not all techniques help the solver define the problem; some formulate the problem into a general form and provide “ready-made” solutions. Some are better at finding the root cause, more appropriate data, or establishing a clearer focus. Some are specifically designed to generate ideas, while others give analytical solutions. Some work well for simple problems, others are designed to tackle complex opportunities.
Understanding the problem to a degree sufficient to select the right techniques when appropriate will save time and yield better solutions by making a more efficient use of the tools available.

Palady and Olyai, authors of the article, “The Status Quo’s Failure in Problem Solving,” address the lack of structured problem solving in industry. The end of their article they recommend not choosing one model, but perhaps two or three: “This process demands the synthesis of different disciplines, statistical techniques and other analytical tools to conquer each problem. Don’t force the problem to the model you have; rather, let the problem select the right model(s)” [39]. The authors echo the previous assertion by recognizing that a process may demand, not one, but many problem-solving models. As the improvement project progresses through each phase, the aspects of the problem may to change or new problems may be uncovered. The authors suggest that the integration of problem solving techniques should be sought, rather than simply choosing one over the other.

6.1.2 Reason Two: Stuck Thinking. Along with the statistical and analytical techniques, creative and/or innovative techniques should be added to the list because not all problems can be solved using statistical or traditional analytical tools. In the case study, the team was having difficulty identifying the most critical part of their process to focus their Six Sigma project. Because the process was continuous and complex, statistical analysis applied then would have been difficult or tedious. Symptoms of stuck thinking revealed that they could not focus the project with the available statistical and analytical tools. However, the theory
of constraints, quickly and effectively aided the team in locating the critical area. Afterwards the team was able to move forward and apply existing Six Sigma tools and techniques.

6.1.3 Reason Three: Change Management. Resistance from company culture and problem dynamics can prohibit process improvement teams from achieving their goal: improving the process. Studies have indicated that “as many as 67% of total quality initiatives and 80% of reengineering efforts have failed to produce their promised results” [22,24]. The reasons for the failures have been attributed to obstacles present in the leadership, a resistant culture, communication, insufficient structure, and the failure to tie improvement projects to business objective [58]. Janet Young’s article, “Driving Performance Results at American Express” lumps these obstacles into category called “the human variable” [58]. She states, “The old adage is correct; work gets done through people, and if you want to bring about transformational change in your organization, you must proactively address the human variable in your deployment efforts” [58]. Wherever there is a need for change, there is resistance due to loss of security or skepticism. This resistance can be so strong that failure to address personnel- and paradigm-oriented problems can result in a failed effort.

Accelerated problem solving tools aid in dealing with the paradigms that lead to resistance, as well as the team dynamics that prevent teams from becoming transdisciplinary in nature, i.e. acting as a unit and working together. Dr. Anne H. Widerstrom et. al. says,
"However, for the transdisciplinary model to work in this optimal fashion the commitment of the team members…is absolutely critical. This means that time must be available and scheduled for team members to meet, to train each other, to share information, and to receive consultation. Teams do not just coalesce when people are assigned to work together. Sufficient time and ongoing support must be given to the process of team development" [56].

However, just meeting regularly does not mean that team members will automatically communicate, especially if unseen forces of political pressure and confusion exist and remain hidden. APS tools, particularly Six Hats and Situation Appraisal help to direct the teams thinking, increase communication and address or avoid these kinds of problems. In the case study, some of the team members had reservations about the politics surrounding the Six Sigma effort and was therefore hampered in fulfilling their team responsibilities. Six Hats Thinking helped to brings those issues to table and increase sympathy and understanding among the team. As a result the project was restructured to circumvent the political pressure while still moving forward with a comparable goal.

Techniques that free the mind of the thinker by organizing thoughts, preserving self-esteem, increasing communication or promote innovative thinking are as necessary to process improvement as the statistical tools present within Six Sigma. The integration of such tools can enable more effective use of existing tools by identifying and/or resolving these types of barriers to process improvement.
Chapter Seven

Recommendations for Future Work

Accelerated problem solving methods should be included in Black Belt and Green Belt training. The tools can be effectively employed after brief exposure. Methods such as the Innovative Situation Questionnaire, K-T’s Specify the Problem, Mind Mapping and the Theory of Constraints can be taught in training at the beginning of the last day of the week with the phases that they are associated in a simple lecture format followed by solving an interactive case study example as a class. Situation Appraisal, Decision Analysis and Six Hats can be completed during the first week of training using role play. These methods can be combined into one role playing session. The instructor can process the learning experience with the class afterwards to highlight the distinctive benefits of each method.

Contradiction Analysis and Su-Field Analysis should be exposed interactively to the class as a whole followed by processing and brief practice in groups of three or four. Members can either work on a provided example or submit a problem from their place of business. If practical problems have been submitted ahead of time, the instructor may choose one to execute with the tools as a final example for the class.

A model for change management needs to be developed and attached to or integrated into Six Sigma. Even with the sufficient infrastructure managing
change is often overlooked which can slow corporate breakthrough. Without that infrastructure, the oversight can result in a failed initiative.

A successful “small-business deployment model” needs to be developed for Six Sigma. Six Sigma deployment is designed to be deployed starting with executive corporate leadership and pushed all the way down to the plant or service associate. Through corporate acquisitions and other various forms of growth, the plants tied to many corporations, especially those in North Carolina, really operate like mini-companies with little involvement from the corporate offices to which they are tied. Guidance is needed for such “companies” that respond to the directive to launch Six Sigma, but do not have strong corporate advisement or support.

An integrated model for the Business Eight of Six Sigma should be pursued. The Business Improvement Strategy of Six Sigma is executed by the executive management of the company. Accelerated problem solving tools could be very useful for locating projects that will be very integral to the company’s breakthrough and future operations.
References


9. Mind Mapping
   Buzan Centers http://www.mind-map.com/mindmaps_howto.htm
   University of Victoria http://www.coun.uvic.ca/learn/program/hndouts/map_ho.html


APPENDIX I

1. Project Slides (includes Fabric Property Run Charts)
2. Process Flow Chart (4 pages)
Reduction of Product Variability
With Identical Standard Process Set-Ups on L2

Six Sigma Green Belt Project
April 7 Through June 3, 2003

Project Team:
Bob
Date
Harley
Ace
Brad

Reduction of Product Variability
With Identical SPI Set-Ups on PA2

Problem Statement:
Subsequent campaigns of material on L2 do not have the same
untufted properties as previous campaigns using identical
process set-ups.
Approx. 5 hours are spent monthly for the adjustment of process
parameters in order to achieve specified product properties on L2.

Mission Statement:
The mission of this project is to identify root cause(s) of shifting in
the L2 process and recommend a course of action to improve
process set-up reproducibility.
Reducing the average time by 50% to bring product properties
into control on L2 will yield a cost savings of $40,000/year.

Data Collection

Output Data:
Physical untufted fabric properties: Weight, Thickness, Tensile
Load, Elongation, Trapezoidal Tear
(Labavantage, QDC, Campaign Books)

Input Data:
Process Settings (SPI sheets)
Process Data (Process run sheets, Temporary Change Orders,
Campaign Closure Database)
Climate Data
??

G 100 on L2

G 100 on L2

G 100 on L2
PA-3 Process Flow Chart

Bulk Chip Storage

Day Tank Storage

Chip Blending

Blend Tank

Crystallizer & Dryer

Color Chip Storage

Color Injection

Extrusion

Polymer Filtration
Pre-Bonding (Calender)

Inspection (Good or Bad)

Lubricant Application

Fabric Drying

Fabric Winding

Master Roll Transfer
Unwind
Stitting
Rewind

Fabric
Inspection

Downgrade

Q1

Roll
Wrapping
And
Labeling
APPENDIX II

1. Innovative Situation Questionnaire (Understanding the Problem, 4 pages)
   2. Cause and Effect Diagram of Undesired Fabric Properties
   3. Cause and Effect Diagram of Desired Fabric Properties
   4. Mind Map of Team Dynamics
Understanding the Problem

It is essential that all parties have a firm understanding of the problem (or opportunity) to be solved. Typically, this phase is assumed, overlooked, and at best represented by differing points of view. (As an example, the stockholders want increased short-term profits; R&D want a new technology; production wants increased efficiency, and engineering wants an improved machine. All of these problems have been phrased as general solutions to different problems. Everyone has a similar goal but different points of view.)

It is critical that the design team agrees upon a common description of the problem. This begins by describing the system and its environment.

1. Information about the system you would like to improve/create and its environment.

1.1 System Name: (Use your terminology)
   Fabric properties of products off of L2 per SPI
1.2 System's Primary Useful Function: (What is the most fundamental action of the system? Use active verb(s) to describe the action between the “tool” and the “work piece.”) Tool = SPI; Workpiece = Desired fabric properties(weight, thickness, tensile load, elongation, trapezoidal tear); PUF: [SPI] produces the expected [desired fabric properties]
1.3 Current System Structure: (Complete all as appropriate)
1.3.1 Process Flow Chart of each operation (include the following with each operation)
   Done. Located in meeting room.
1.3.1.1 Useful Function(s) (use tool acts on work piece language)
   The tool produces the workpiece.
   The tool supplies the workpiece.
   The tool yields the workpiece.
   The tool delivers the workpiece.
1.3.1.2 Harmful Functions(s) (use tool acts on work piece language)
   The tool yields waste and second quality (lost revenue)
   The tool produces wastes and second quality
1.3.1.3 Waste(s) (energy, material, fluid, manpower, etc.)
   Wasted material, second quality, lost revenue, wasted time, wasted energy, chip, $80,000/yr, 60 man hours a year.
1.3.1.4 Cost (use a common $ value system, such as $/part) $___/roll
1.3.2 Process Flow Timing Chart (time to convert incoming product into exiting product) Need to complete
1.3.3 Part/component diagram with function(s) of each part (similar to an assembly drawing) N/A
1.4 Cause and Effect Analysis (human, machine, environment, methods, materials)
1.4.1 Useful Function Cause & Effect Diagram to complete “Primary Useful Function”
   Completed
1.4.2 Harmful Function Cause & Effect Diagram that hinders/prohibits completion of
   “Primary Useful Function” (Note: The same cause can occur in both diagrams)
   Need to complete electronically.
1.5 System Environment (Super and sub-systems that influence “Primary Useful Function”)
1.5.1 List Super Systems (trends; more general systems in which the primary system is
   a component)
   All physical properties    All three lines
   The company as a whole
1.5.2 List Sub-systems (components of the primary system)
   Stages of production    Color chip    Testing equipment
   Individual properties    Each piece of equipment
   Each raw material vendor Personnel    Testers
   Inputs                 Calibration    Environmental factors

2. Available Resources

Available resources are often overlooked for use in the solving the problem.
Systematically identify “free” resources. These resources include energy fields, wastes, information, space, and time.

<table>
<thead>
<tr>
<th>Energy Fields</th>
<th>Wastes</th>
<th>Information</th>
<th>Space</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving air</td>
<td>butt cuts</td>
<td>Email</td>
<td>Silos</td>
<td>Meetings</td>
</tr>
<tr>
<td>Humidity</td>
<td>edge trim</td>
<td>SPI database</td>
<td>Warehouse</td>
<td>Waiting for</td>
</tr>
<tr>
<td>Gravity</td>
<td>waste water</td>
<td>Sister plants</td>
<td></td>
<td>decisions</td>
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<td>Static Electricity</td>
<td>wasted lubricant</td>
<td>Operators</td>
<td>Financial reports</td>
<td>Style changes</td>
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<tr>
<td>Ambient</td>
<td>monomer/oligomer</td>
<td>SAP</td>
<td></td>
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<tr>
<td>Temperature</td>
<td>chip during sampling</td>
<td>Labvantage</td>
<td></td>
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<tr>
<td></td>
<td>Dump air</td>
<td>QDC</td>
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<td></td>
<td>Steam</td>
<td>Campaign books</td>
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<tr>
<td></td>
<td>Dust Chip</td>
<td>Temporary Change Orders</td>
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<td></td>
<td>Unused heat</td>
<td>Climate Data</td>
<td>Process run sheets</td>
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<td></td>
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<td></td>
<td>Campaign Closure Database</td>
<td></td>
</tr>
</tbody>
</table>
3. **Information about the problem situation.**

3.1 Describe the primary improvement you would like to make to the system.
   - Enable reproducibility of fabric properties

3.2 Describe the main drawback or cause you would like to eliminate.
   - Wasted materials and resources that result in loss of time and revenue.
   - Eliminate or reduce variability

3.3 Describe the mechanism that causes the drawback; include the conditions and circumstances under which it occurs. (Identify the root cause of the problem if possible.) **Unknown.**

3.4 Describe the history of the development of the problem. (What lead to the problem? Consider a path of development that would have avoided the problem.)
   It appears that there are several reasons why this problem has developed. They are listed below:
   - The technology was developed in off site. The design did not fully consider the in-house conversions.
   - The original line setup was not fully communicated due to communication difficulties and differences in software and technology
   - SPIs may have designed without considering a sufficient amount of factors.

3.5 Other problems to be solved. (Is it possible to modify the direction of the development so that the events leading to the drawback can be eliminated?)
   - General line inefficiencies
   - Same problem on other two lines
   - Other forms of waste production
   - Obscurity of some critical points of line operation
   - Lack of documentation of line operation

4. **Change the system**

   **Must be discussed and determined by the steering committee**

4.1 Allowing changes to the system (Evaluate and describe the degree of possible change to the system that is achievable as a result of the problem solving process. Is a major change possible? Major changes are typically justified based stage of the technological life of the system, the need for revolutionary technology, and the economic justification for solving the problem.

4.2 Limitations to changing the system. (In most production situations, major changes are not normally feasible due to economic limitations and existing process restrictions. Determine which technical, economic, production, quality, or other characteristics should govern the design? Should these parameters 1) remain constant, 2) increase, or 3) decrease? Explain reasons for the limitations.)

5. **Criteria for selecting solution concepts**

5.1 Desired technological characteristics
   - The team desires to gain a better understanding of factors that affect line operation and find SPIs that are more robust and can produce the desired fabric properties despite changes in raw material and ambient temperature and humidity.
5.2 Desired economic characteristics
   The hope is to achieve the above using equipment already in place without incurring much more costs.

5.3 Desired timetable for implementation
   By the end of quarter

5.4 Expected degree of innovation (patents)

5.5 Other criteria.


6.1 Previous attempts to solve the problem. (Describe the previous attempts to solve the problem. Document the reason that earlier attempt failed.)
   No attempts

6.2 Identify similar system(s) in which a similar problem exists. (Think about the “primary useful function.” Where is the primary useful function performed in other industries? Has the problem been solved in another industrial field. Most innovative patents use a scientific effect that has been successfully commercialized in another industrial field. This “process of analogy” is the most commonly used method by the best inventors.)
   This problem exists for each line. Team indicated that there is a problem when attempting to communicate with sister plants, particularly their counterparts at the other plants. This aspect needs to be looked to more closely.
Cause and Effect Diagram of Undesired Fabric Properties per SPI

- **Measurement System**
  - Lab climate not cont
  - Frequent online qual

- **Materials**
  - Variation in color c
  - Variation in PET
  - Variation in CoPET
  - Varied amount of qua

- **Personnel**
  - SPI not followed
  - Lack of communicatio
  - Low operator repeati
  - Differences between
  - Differences between
  - Design differences
  - Management
  - Varied consideration
  - Low run frequency
  - Low run length

- **Environment/Maintenance**
  - Improper Cleaning
  - Not done on time
  - Bad line condition
  - PM
  - Changes in lab clima
  - Static Electricity
  - Humidity
  - Temperature
  - Weather

- **Equipment/Process Setup**
  - Design capability
  - Equipment modificati
  - Process changes
  - Ignoring equipment c
  - Lack of process opti
  - Process capability
  - Order of setup
  - SPI not followed clo

- **Unspecified Settings**
  - Unknown
  - Left up to line mana
  - Settings not able to
  - Settings are not cap

- Undesired Fabric Properties
Mind Map of Team Dynamics

Finance Dept
Access to SAP Info
Brad
Aid Politics
CAUTIOUS
Project Team Goal: Process Improvement

Harley
Product Development
Gathers Historical Data
Eager to Move Forward
Red Dept Line

Bob
Find more MFG related Process Data

Dale
Team Leader

Ace
Production Supervision Linez

Maintenance & Engineer

Robust Process

Maintenance & Engineer

Team Dynamics Key
8.27.03

- = connection, the thicker the line the greater the enthusiasm

= interests

= my concerns

~ = consistent, strong

= information

= time commitment

= member