Silicon Valley Engineering Council Journal

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Volume 2

SILICON VALLEY ENGINEERING COUNCIL

The Alliance for Engineering Leaders in the Silicon Valley

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Mission

Founded in 1989, the Silicon Valley Engineering Council is a nonprofit educational institution. Its purpose is to assist its member technical societies in Silicon Valley to better serve our members and the community.

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AFE, Association for Facilities Engineering, Silicon Valley Chapter
AIAA, American Institute of Aeronautics and Astronautics
AIChE, American Institute of Chemical Engineers
AISES, American Indian Science & Engineering Society
ASCE, American Society of Civil Engineers, San Jose Branch
ASMI, American Society of Materials, International
ASME, American Society of Mechanical Engineers
ASQ, American Society of Quality
CPMT-IEEE, Components, Packaging, & Manufacturing Technology
EAA, Electric Auto Association of Silicon Valley
EWB-USA, Engineers Without Borders-USA
IEEE-SSC, IEEE-Solid State Circuits
IEEE-NANO, IEEE San Francisco Bay Area Nanotechnology Council
INCOSE, International Council On Systems Engineering
ISQED, International Society for Quality Electronic Design
NATEA, North American Taiwanese Engineers' Association
SAE, Society of Automotive Engineers
SAMPE, Society for the Advancement of Materials and Process Engineers, Northern California
SBAY, South Bay Community Network, Inc.
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STC, Society for Technical Communications
SWE, Society of Women Engineers

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From the Office of the President

Silicon Valley, even though known worldwide with this name due to its legacy of being the furnace of silicon semiconductor engineering over the past decades, has transformed itself into a multidisciplinary incubator mega metropolis, with leadership in diverse areas like software engineering, biotechnology, aerospace, defense and nanotechnology. Leaders in search engine technology like Google and Yahoo have come out of this valley, while social networking companies built on the foundation of web technology have thrived with many user and developer groups springing and blooming almost every month in routine meetings and conferences. Many companies in biotechnologies have been born in our valley, developing the most advanced processes and products. Nanotechnology companies have developed some innovative materials, composites and products applicable to many engineering areas and markets. Silicon Valley has grown up to be an engineering valley.

Silicon Valley Engineering Council (SVEC) truly represents this multidisciplinary environment, having continuously brought and nourished scientific and engineering societies of diverse yet complimentary areas, with a gamut of programs and events. Last year, we started the SVEC Journal which traced the history of Silicon Valley in the inaugural volume and covered different aspects the valley. In this volume, the Editorial Team, under the leadership of Dr. Amip Shah has chosen to feature articles in diverse technology areas and also about leadership in engineering. For example, one of the articles presents the role of plastics in the advancements in semiconductor technology over the decades. The green building movement is bound to change the way buildings are designed or retrofitted. An article covers this important environmental engineering field that could change the building design in the following decades, not only in USA but around the world. Another article covers the emerging field of structured innovation.

This second volume of the SVEC Journal is a reflection of the variety of scientific and engineering societies in SVEC. The disciplines of the societies are becoming complex but interdependent on each other. We are glad that the SVEC organization, its events, programs and activities, including this very journal, supports and nourishes these healthy and symbiotic growth modalities of interdependence.

I thank the Editorial Team and the individual authors for bringing this scholarly journal. I would like to encourage everyone to read the articles and provide feedback to the editors, authors and directly to me and the SVEC officers.

Dhaval J. Brahmbhatt
President, SVEC

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Editor's Note

It gives me immense joy to bring to you this year's edition (Volume 2) of the Silicon Valley Engineering Council (SVEC) Journal.

Last year, in the inaugural volume of the SVEC Journal, Dan Donahoe presented six articles that traced the history of Silicon Valley and reflected upon its various areas of expertise – from next-generation cities, to a century of flight at the NASA Ames Research Center, to the fundamentals of IC Packaging and Interconnection technology. In discussing our plans for this year's volume, we wondered what we could do to improve upon one of the best overviews of all the exciting technologies that Silicon Valley has given to the world.

After months of wrangling, we concluded that we couldn't. While we could invite another set of experts to discuss the depth of technological expertise in Silicon Valley, it wouldn't be as exciting. Instead, we have chosen to focus on the breadth of activities that occur throughout the Valley and across SVEC member organizations. Most people inherently associate Silicon Valley with technology, particularly silicon- and semiconductor-based technologies. And while that may indeed reflect the origins of Silicon Valley, it hardly represents the limits of Silicon Valley.

So this year, we bring you four articles – each highlighting an aspect of Silicon Valley that might surprise you, each which presents a perspective that you may find helpful as you move forward.

First, Silicon Valley is certainly among the world's best in terms of engineering, and we have some of the world's best and brightest amongst us. But, what people often forget is that we are also among the world's best and brightest *leaders*. Perhaps nobody else has been as successful at putting out technologists who can successfully inspire not only their organizations but entire industries. What's the secret sauce? Steven Cerri provides his perspective on the transition from engineers into managers and leaders, and how it involves thinking 'one level above'.

Next, it is a readily known fact that some of the world's greatest innovations in silicon happen – where else – but in Silicon Valley. Stop and think, though, about all the innovations that must happen *around* silicon to enable our technological advancements to reach commercial fruition. Plastics is often hardly regarded as a material at the cutting-edge of technology, but Dr. Dan Donahoe and Dr. Michelle Poleskie explain how expertise in plastics is a key ingredient of the advancements that we have seen in semiconductor technology over the decades. In the opinion of one of our technical reviewers, this article "provides a wonderful introduction to a little-appreciated but highly critical field in Silicon Valley."

As the world struggles and pushes to address challenges associated with climate change, Silicon Valley will once again be at the forefront of innovation. Beyond a doubt, the venture capital and entrepreneurial culture in Silicon Valley presents an outstanding opportunity for start-up companies in the Valley to enter what may very well become one of the most exciting technology areas in the decades ahead. But, as our third article discusses, the excitement is not going to be just about renewable energy, efficient devices, or new materials: a huge opportunity for change is coming in one of the oldest areas of technological innovation – buildings. Shalini Singh provides an overview of the landscape and the opportunities related to 'green buildings'.

And lastly, but certainly not least, the heart of Silicon Valley: innovation. A topic near and dear to everyone associated with SVEC, but one that has not been very well understood: what makes Silicon Valley such a hotbed of innovation, and in an increasingly globalized world where a sizable population is trying to emulate tangible features of the Valley, how can we keep our differentiation? Scott Burr and Dayna Hubenthal seek answers to this question in the emerging field of structured innovation.

Let me conclude by thanking all those who have made this year's journal possible. Dan Donahoe, Past Editor, for the guidance and inspiration in making the SVEC Journal continue into its second year. Elise Engelhardt, past SVEC President, for welcoming me as the 2010 Editor. Dhaval Brahmbhatt, current SVEC President, for giving us an unfiltered outlet to share our views. Janet Ward, for her never-ending and smiling assistance. And, of course, all of our contributing authors: the type of passion, expertise and leadership you have displayed is a glimpse of what makes Silicon Valley such a wonderful place.

I hope you will enjoy reading this issue as much as I have enjoyed putting it together for you.

Sincerely,

Amip Shah
Editor
SVEC Journal
Vol. 2, 2010

Table of Contents

Author Bios

Scott Burr

Scott Burr is Co-Founder and Principal Innovation Consultant for Hubenthal Burr Associates (HBA). He is a thought-leader for the emerging field of Structured Innovation and is a certified Six Sigma Master Black Belt. Scott is HBA's lead facilitator & trainer applying Structured Innovation, TRIZ and Six Sigma to real world problems. He has been actively involved in these fields since 1998.

Prior to founding HBA, Scott worked at Space Systems/Loral, a leading full-service satellite manufacturer. He served in the roles of Senior Process Improvement Specialist, Section Supervisor and Process Manager. By leading the charge towards Lean Manufacturing and Six Sigma in the high-reliability electronics manufacturing area, Scott oversaw productivity improvement by a factor of six over eight years. As key initiator, strategist, and team leader in this challenging environment and using culture integration strategies, Scott positioned the electronics assembly department at Space Systems/Loral to compete in a consolidating industry.

Mr. Burr is the Professional Development Chair for the American Society of Mechanical Engineers (ASME) for Silicon Valley and for the Pacific Northwest District. He facilitates and arranges professional development and leadership courses for thousands of engineers. For the past five years, Scott has also been the Head Leadership Trainer for the North American Pacific Coast for the ASME.

Scott received a B.S. degree in Mechanical Engineering from Stanford University. He earned his Six Sigma Black Belt and Six Sigma Master Black Belt certifications from the Juran Institute and Breakthrough Management Group respectively. His personal interests include medicinal nutrition and the ancient cultures of Hawaii.

Steven Cerri

Since 1999, Steven has helped thousands of technical professionals enhance their communication, management, and leadership skills through innovative training programs, coaching, published articles, an IEEE-published book, and a popular blog on his website, www.stevencerri.com. As a sought-after speaker in the United States and internationally, he has presented at numerous industry associations including AIAA (American Institute of Aeronautics & Astronautics), ASME (American Society of Mechanical Engineers), and IEEE. An adjunct professor for the Technology Management Program at the University of California, Santa Barbara, he teaches critical communication and business/entrepreneurship skills to graduate students. Some of his clients have included ViewSonic Corp, GeoGraphix (a division of Halliburton), and Ball Aerospace and Technologies Corporation.

Steven began his career as an aeronautical engineer employed at Rockwell International Corporation working on Skylab, Shuttle, Shuttle Tug, and meteorological satellite programs. Throughout his career, he has managed individuals and teams in government and commercial organizations. He was part of a team that launched Infotec Development, a successful computer systems integration firm focused on Department of Defense programs. It was eventually bought by Pacer Systems; now part of the Titan Group. He has been a program manager, director of corporate training, vice president of engineering, chief operations officer, and divisional general manager. With a passion and expertise for teaching others, he eventually launched his own consulting and training organization to assist technical organizations that want their engineers and technical managers to be as effective with people as they are with technology.

Daniel Donahoe

Dan served as 2007–2008 chair of the IEEE Components, Packaging and Manufacturing Technology Society (CPMT) Santa Clara Valley Chapter. The chapter was granted the 2008 CPMT Chapter of the Year Award. He has served as an Associate Editor for the IEEE CPMT Transactions since 1998. Dan is currently serving on the Board of Governors for IEEE CPMT. He was a Director of the Silicon Valley Engineering Council and introduced the inaugural edition of the 2009 SVEC Journal. Dan worked in industry at Lockheed, Motorola, Ford Aerospace, Teledyne, Compaq Computer, Iomega and Exponent. Exponent was granted the 2008 IEEE Region 6 Central Area Outstanding Corporate Service Award. Dan has a number of publications, granted patents and has provided many public technical presentations. He has a PhD from the University of Maryland, MBA from Santa Clara University, BS and MS from the University of Illinois. He is a registered professional engineer in Arizona, California and Utah and is a certified reliability engineer. Dan is an active member of several additional SVEC societies including ASME and ASQ and other technical societies yet to join SVEC.

Dayna Hubenthal

As Co-Founder and Principal Innovation Consultant for Hubenthal Burr Associates (HBA), Dayna is responsible for developing implementable breakthroughs on-demand using Structured Innovation. She is applying her knowledge of innovation to the medical device, veterinary and healthcare industries. She has been actively involved in the fields of Structured Innovation and TRIZ since 1998.

Ms. Hubenthal is HBA’s media and marketing guru. Dayna also helps coordinate activity for Hubenthal Burr Associates’ innovation research projects, where she has broad responsibility for innovation thought-leadership in the fields of change management, leadership, and social systems. HBA is interested in collaborative innovation and building coalitions of committed partners to apply innovation to areas of high social importance including health care, education, energy independence & the environment, public safety, and quality of life.

Dayna received her MFA in Fine Art from San Jose State University after 15 years of diverse study including English, Environmental Studies, and Industrial Technologies. Her passion for art and its relationship to language, to influence & to technology has given her a deep understanding of creativity.

Michelle Poliskie

Michelle Poliskie works at Solyndra, Inc., a local Silicon Valley start-up. There she specializes in process design and material selection of plastics and elastomers. She is a former lecturer at Johns Hopkins University where she taught polymer synthesis, commercial formulations and characterization techniques used to solve problems related to the identification of chemical compatibility and degradation pathways. Michelle holds a Ph.D. in Polymers from Massachusetts Institute of Technology and dual bachelors degrees in chemistry and economics from Grinnell College.

Shalini Singh

Shalini has over six years of multifaceted experience in design development, LEED® certification, energy efficiency, construction management and corporate real estate for multinational high tech companies. Shalini has worked across corporate groups and in diverse roles spanning finance, operations, and management consulting. This range of experience enables her to bring a holistic perspective to the current state and the future of buildings. She is an avid reader on climate change, smart grid, green buildings, and sustainability. She also has a blog at www.grnfy.com. Shalini completed her Bachelor in Architecture from VNIT, India, a Masters in Building Engineering and Management from SPA, India, and an MBA from San Jose State University. Her most recent experience has been in advancing corporate sustainability initiatives at Applied Materials. Shalini currently works with Sustainability and Energy Management team, implementing energy conservation and efficiency projects at Stanford University.

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Creating High Performance Engineering Teams
Turning Engineers into Leaders

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Engineers are not natural leaders. In any "natural sense", as a group, they may actually be farthest from that label. Generally speaking, not only are engineers not natural leaders, most have never wanted to be nor have they been trained to be leaders. While there may be a few engineers who have certain innate tendencies toward leadership, the vast majority have neither the personality, the desire, nor the training to be. By disposition and training, engineers take orders and provide answers to questions and problems; and they are expected to provide the "right" answers. Their careers, identities, and professional success are dependent upon providing these "right" answers on time and in budget.

This is why engineers go to school; to learn how to find and determine the "right" answers. This is what we have when we have completed our education; the knowledge and ability to find and determine the "right" answers. This is what our diploma indicates we are capable of. This is why we spent all that time in preparation.

So why is it then, after all this preparation, our companies and organizations want and expect something different from us? Said differently, what exactly is it that organizations and companies want from their engineers?

Introduction

Few organizations want their engineers to just "do their thing"; to just take orders and come back with the right answers. Few organizations want their engineers to remain "just technical". Most organizations want their engineers to be more than technical. They want them to contribute more than their technical expertise, only.

Most organizations and managers want "Fully Integrated Engineers™". That is, engineers who can be fully integrated into a team and who can contribute fully to the organization, not just their engineering talent but also their ability to use their minds to contribute to the broader organization. They want from their engineers something that their engineers were not prepared to do nor trained to do.

In fact, if engineers want to advance and if managers want high performance engineering teams, managers must motivate their engineers to step out of the mode of thinking only like an engineer, and engineers must be willing to think beyond their engineering mentality. To have high performance engineering teams, the manager must teach the engineers how to think beyond engineering—instead how to think at least one level above their current engineering level.

<u>An example of thinking one-level above</u>

I am currently coaching an engineering manager in a high technology aerospace company. I have been coaching her, off and on, since she first told me she wanted to move from engineering into management nearly 10 years ago; she first became a manager five years ago. She is now a very successful, mid-level manager, with her own department. (Yes, it took five years for her to move from engineering into full management. Take note, all the young engineers who want to be promoted to manager status after your first assignment out of school! Becoming a manager doesn't happen over night.)

She has, over the past several years received promotions and accolades for the successes of her teams. She recently received high praise from one of her customers and when company executives found out about this praise, they in return, praised her and her management skills. Her boss however, while praising her for her success, responded by also congratulating her for making a good profit for the company.

She did not think much of her manager's comment, but I did. While he praised her for the success on the project, he did add the congratulation for making a good profit. From my perspective the message was, "Good job *and* my focus is on the profit". The sub-text is, "High customer praise for a program that doesn't make a good profit for the company is no praise at all".

You can rest assured that my next management coaching session with her will be focused on exposing her to the need to now focus on the profit she can bring to the company as she successfully manages her programs. Her manager has sent a subtle but very clear message that her next level of thinking should be on program profit. She will now be required to adjust her "conversations" so that she begins to have conversations with her manager around the concept of profit. She will begin to manage at least one level above her level, and that will require that she think about and focus on program and corporate profit, which is where her manager's focus is.

This is what I mean by "thinking at least one level above". Engineers as well as managers must think at least one level above their current level in order to advance in their organizations.

Engineers must think a level above

The example above is a concrete, real-world example of what thinking one-level above means; in this case for a manager. However, it is critical to anyone who wants to advance his or her career, especially engineers. Engineers must begin to think beyond their own obvious focus. They must begin to incorporate a broader view that includes themselves, their colleagues, their customers, other departments, other processes, and their managers.

In turn managers must help their engineers to understand what it means to be thinking one level above. It is the manager's responsibility to provide an environment where discussions and interactions can take place that address areas beyond the immediate focus of the engineer. (In the example I presented above, I would have been much more specific than this manager. If I wanted my direct report to focus on profit, I would have said so in a clear discussion, not as an after-thought to an email of praise.)

Let me give you several straightforward examples of behaviors that managers should foster and engineers should display. These behaviors are often counter to what engineers are taught in school, but these behaviors are absolutely required for long-term success inside organizations.

Trait #1: Disconnect your identity from the success of your ideas

Most engineers, as they progress through college, are graded on whether their ideas are good ideas or poor ideas. I remember one of my first assignments in my first engineering course. The assignment was to design a system for the projection of ideas in a group presentation.

Well, what was the underlying message? If I presented a poor idea, I would have received a poor grade. If I presented a creative idea, my grade would probably be higher, assuming in both cases my design drawings and considerations were reasonable and in some fashion, equivalent.

Therefore, from my very first year of engineering school, the subtext was that "The degree to which my ideas were 'good' was directly related to my success as an engineer". "If my ideas are good I must be a good engineer." "If my ideas are not so good, well, maybe I'm not such a good engineer."

Now you might say, "Well, what is so bad about that? Everybody gets judged on his or her ideas. Why should an engineer not be judged on the merit of his or her ideas?"

The answer is that, in most cases, that is not what a company or organization wants. Organizations do not want engineers who believe their ideas are tied to their identity. Let me explain.

While I'm not arguing against judging the merit of ideas, I am saying that our ideas should not be so closely tied to our identity that we defend them even when they are no longer good ideas. The engineer who believes that their identity is tied to their ideas may be very unwilling to sacrifice even one of their ideas even as that idea fails to remain valid under scrutiny.

Blind defense of your ideas is what happens when you feel your identity and your ideas are closely linked. I see it happen all the time and you probably do as well. It happens at every level of an organization. In a meeting someone puts forth his or her idea and it is immediately questioned. They answer a few questions but the questions don't stop. The idea is being attacked from all sides. The originator now feels a little defensive and may even feel "cornered". Instead of stopping and reflecting on the questions, the originator continues to defend his or her idea. The defenses become more elaborate. At some point it is clear to everyone except the originator that the explanations no longer make a great deal of sense and it's all about defending the idea. The discussion takes a different track and the process ends without resolution.

What we really want from our engineers instead, what we really want as managers of high performance teams, is to have our engineers contribute their best ideas and work together with others to refine and develop the best "composite idea" from all those that have been contributed.

It may be very useful to fight for our ideas if we are research scientists working relatively alone in a research facility. But most of us don't work that way. Most of us work on teams, and our ideas are just one idea of many that must be contributed and refined in order to develop the final, successful idea. It is a willingness to work with others and to contribute constructively that most managers are looking for and that are the hallmarks of high performance engineering teams.

So, as a manager of high performance engineering teams, I do not want engineers who fight for their ideas to the exclusion of common sense or cooperation. I want engineers who contribute their best ideas, and then work with others to refine and redefine their ideas in order to construct the very best idea from all the ideas that have been placed on the table.

Trait #2: It is better to be effective than it is to be right

As I indicated above, most engineers are trained to seek the "right" answer. The fact is that throughout our college years there were not many times, if any, where we took "blue-book, essay" examinations. Our engineering examinations were not dependent upon our ability to "argue" our point of view convincingly. Our examination answers were either correct or they were not. In fact, we often got partial credit for setting up the problem correctly even if we were unable to finish deriving the complete answer by the end of the examination period. So our education conditioned us to find the "right", the "correct" answer.

However, in many "engineering applications", in many situations "in the real world" there may be several possible answers to a complex engineering problem. There may be several ways to accomplish a specific "something". Therefore, there may not be a "right" answer; there may be several equally "effective" answers.

For most relatively young and less experienced engineers, being effective just "doesn't compute". They think, "Isn't the right answer what I'm supposed to provide?" "Isn't my annual or semi-annual performance review dependent on the fact that I provide the right answer?" Well, only if it doesn't conflict with any other "right answers".

From the manager's perspective, most managers don't want a group of engineers sitting around a conference table arguing about why their answer is the right answer. The manager would rather have a group of engineers arguing about the most effective, results-oriented answer. Managers want their engineers to function as high performance teams, and that means that each engineer is looking for the most effective way to integrate their idea and their answer with other ideas and other answers to achieve an overall result.

Trait #3: How you communicate something can be as important as what you communicate

Most engineers are taught and are convinced that data speaks for itself. Information, data, the right answer does not need to be sugarcoated. It does not need to be presented in an "appropriate" fashion or package. It can be laid out cold and clear, and it will obviously stand on its own.

Most engineers don't understand that how something is said and presented (and here I am *not* referring to good or bad "powerpoint" presentations) can make all the difference in the world regarding how it is accepted. The verbal communication processes that are used to communicate ideas as well as data are critical to having those ideas and data heard and perhaps accepted. Many of my coaching sessions are specifically around the fact that many engineers do not understand that the way something is said and communicated can be as critical as what is said.

<u>Trait #4: Think systemically. You are not paid to just do your technical work</u>

Many engineers believe, erroneously, that they were hired to perform a specific technical job and that their technical job should be their focus. However, most organizations don't want their engineers to be "human silos". They do want their engineers to think beyond their immediate technical world.

Engineers, generally, consider themselves professionals. They consider other engineers to be as professional as they are. This means that since they intend to do a good job, they also assume that the other engineers will do a good job. Therefore, "getting into" someone else's world is not a good thing; it can be perceived as intrusive. It smacks of micromanagement or of not trusting that the other engineer will do a good job.

However, all engineers are not created equal. All engineers should not be trusted to do the same level of work. And therefore, the engineer on a high-performance team, the engineer that the manager wants, is one who is capable of respectfully questioning and understanding how their personal work will or may impact the work of other individuals, areas, groups, departments, and/or processes in the company and the customer, and vice versa.

This is what it means to be a "Fully Integrated Engineer™" and to be part of a high-performance engineering team. The engineers on these teams think about how their work will impact others.

Once again, no manager wants engineers who can do and think about only their specific task. Managers are constantly looking for engineers who can think beyond their immediate world, who think of the technical world as a broad "system". Engineers who have the eye of their manager, who will advance quickly, "think systemically".

<u>Trait #5: What got you here will not get you there</u>

Most engineers believe that what got them to their current status or level will get them to their next level of success. The general thought is, "If I just do my current job well, if I just work the way I did in the past, which was obviously successful, I'll get promoted".

While the above statement may be true in some organizations, it is ultimately the wrong path to long-term success. Many managers will promote an engineer for doing their job well only because they have the mistaken concept that if an engineer can do their job well they "should be able" to manage others doing similar work. This is seldom true but it is often attempted.

The fact of the matter is, if you prove that you can do your current job well, it only proves that you can do your current job well: nothing more, nothing less.

If you want to prove that you are someone to promote, you must do your current job well *and* you must show that you think systemically *and* that you think at least one-level above.

Therefore, as a manager, I am always looking for people who can think beyond their current work and into the worlds of other departments, other groups, and other technologies, and who can have the conversations that will make the difference in how things get done.

Building high performance engineering teams takes both engineers and their managers

In the final analysis, if managers want to build high performance teams and engineers want to advance their careers, the participation and commitment of both the engineers and the managers are required.

Engineers must begin to understand that their "engineering education" did not end with college. By this I mean that their technical education *and* their non-technical education should continue past graduation, and by far, the most critical education which should take place is the non-technical portion.

Second, engineers must understand that their non-technical education will feel like a totally new career. That is because many of the aspects of life they sought to avoid by becoming an engineer not only can't be avoided, but also will now become important. These aspects include working with people, communicating effectively, dealing with conflict, performing non-technical tasks, and so many other tasks that we would classify as non-engineering work.

Finally, engineers must understand that their interests must begin to grow beyond engineering. They must have "conversations" with others, especially their management, on topics that are important to management. It is critical that engineers begin to show they are capable of understanding and conversing in areas that are not the domain of engineering. These include finance, profit, budgeting, schedules, task definition, resource allocation, presentation development, and many others specific to your company.

The managers must contribute their part as well. And for managers this challenge can often be more daunting than for the engineer, because the engineer is often dealing with one manager while the manager is dealing with a number of direct reports.

The manager's job is to provide an environment where feedback and guidance can provide the needed direction for the engineers to contribute effectively and learn and grow. It is the manager's job to "groom" those engineers who are capable of advancing ,and provide a place for those engineers who are not yet ready or want to remain engineers.

Notice The World Around You

As an example of what organizations want and need, just look around at the high-tech companies in the Bay Area. The histories of technical companies in the Bay Area are littered with engineers who started companies and ultimately were pushed out of the top slots. I will avoid listing those engineers, but you probably know of some.

No doubt, there are those engineers who have been successful and have remained the leaders of their companies; and they have done so because they have been more than technical.

In those cases where the engineers have lost control of their companies, we might like to attribute their removal from the top position in the company they founded to the greed and drive of those who ultimately took their place. However, a more accurate explanation in most cases is that the founding engineer could not "become" what the organization needed in a leadership or management role.

Next time you read a biography about a high-tech company founder or the history of a high-tech company, pay attention to the "evolution" of the founder or founders. Notice who stays an engineer and who evolves. Did they evolve and how did they evolve? If they didn't evolve, did they hire people to back-fill their limiting capabilities or did they get pushed out?

Silicon Valley is filled with legends of all stripes. There are stories of the engineers who founded a company in a garage and went on to be part marketers, part business people, and part engineers. They kept their company. There are stories of the partners who founded a company in a garage and of the engineer who did not want to morph and was ultimately pushed out. And there are stories of the young programmers who built a company and hired people to do what they didn't want to do or couldn't do.

Now you can use the characteristics I've listed in this article as a new set of lenses through which to notice the behaviors of successful and not-so-successful engineers in the long run. The evidence for the information I've presented in this article is all around you. Now you can notice it.

The fact that there are so many engineers who don't successfully embrace the characteristics I've presented here is testimony to how difficult it is to become more than an engineer. And the reason for this is relatively complex. I believe we select our careers because they allow us to move through the world the way we want to. Our careers allow us to "be who we want to be in the world" and to be "successful" in the ways we want to be successful.

Therefore, to adopt a new way of "moving through the world" is a very big deal. It requires a change in our identity. It requires a change in "who" we perceive ourselves to be. This change is very difficult to achieve on our own. It requires a framework, a structure, and processes that will allow us to change and be supported along the way. This change process, the process of becoming more than technical, is best implemented and supported through coaching. The engineer must be coached on an on-going basis as his or her identity is expanded beyond being an engineer. Coaching also is a critical function of a manager or leader because it is a necessary process in building high performance teams. But this topic is for another article or maybe a book.

Conclusion: On Building High Performance Engineering Teams

Building high performance engineering teams is a challenge. If it were easy, everyone would be doing it. It requires engineers who are flexible enough to understand that their job is to be more than "just an engineer". It requires managers who understand how to bring out more than "just the engineer" in his or her direct reports. It requires a level of communication expertise that frankly, most managers don't have. They must be trained and coached in this skill.

For those engineers who want to advance beyond engineering, being a Fully-Integrated Engineer™ and being able to contribute on a high-performance team is the first step on the path to management. It requires being open and capable of communicating beyond their immediate area of interest and it requires a flexibility that is not generally taught in school.

However, the advancement of one's engineering career and the building and managing of high-performance engineering teams, are all within the grasp of most organizations. It is just a matter of taking that leap into a new and different way of being an engineer and an engineering manager.

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Plastics in Electronics

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This article elicits the materials perspective of technology to explain that plastics are an underappreciated contributor to modern digital electronics. Too often in Silicon Valley, people become fascinated with what appears to be the most recent success. One of the key successes in the Silicon Valley of the 1970s and 1980s has been the development and promulgation of the integrated circuit. In the late 1990s, firmware and software, companions to IC based systems, became the darling of investors. While many kept their eyes focused on great IPO successes, the engineers and scientists worked to perfect new materials and new applications that made these successes possible. It is appropriate that the SVEC Journal, published during National Engineers Week, ground perspective back to the basics of the quiet diligence of engineers and scientists. Their contributions make technical advances, and riches for some, possible, because their new innovations in basic technologies drive future growth and create new fortunes.

Keywords: components, moisture, polymers, electronics, innovation

Introduction

Silicon Valley owes its name to an element on the periodic chart [1]. Therefore, it is fitting that an article in the Silicon Valley Engineering Council (SVEC) Journal be dedicated to materials used in electronics. In fact, the materials view of technology is so embedded in our view of ourselves that we sometimes overlook how materials impact all of mankind. In the social sciences, archeologists define almost the entire history of mankind as the “stone age”, the “bronze age” and “iron age” with our modern “historical” period being less than one-tenth of one percent of human history [5]. Social scientists teach us that humans are technologists, and, as technologists, we use materials to make tools.

Man did not enter each of these archeological ages, develop technology and depart into the next age empty-handed. The Stone Age lives on today, but we call the study and use of minerals by the name ceramics. Similarly, we call the study of bronze and iron and all metal alloys by the name metallurgy. Beyond continuing to improve the use of stone and metal in our modern era, man has invented new materials. One of those new materials goes hand-in-hand with exploitation of petroleum in the internal combustion engine. This paper focuses on the polymeric products we call plastics. Some well meaning people demonize plastics as an unnatural material, but human development and use of plastics is an experience congruous with historic development of stone and metals. Just as man refines naturally occurring ores to produce metal alloys and ceramics, so man has learned to create commercial polymers that are refinements of molecules that occur in nature.

Plastics were first formulated in the nineteenth century and early twentieth century, and became widely used commercially in the early twentieth century. This timeline is similar to the origins of radio and the subsequent development of electronics. This article will explain how plastics are used in electronics products and will show how integrally plastics grew with electronics technology advancements. To quote Charles Harper’s Preface in his 1964 book: “The application of plastics to the design of electronic and electrical products presents some of the most interesting challenges to be found in these industries... the use of plastics offers practical solutions for most of the insulating, packaging, and structural problems associated with the design of electronic and electrical systems" [12]. Today, no modern electronics product could exist without plastics.

In American popular culture, a famous line echoes from the fabulous 1967 coming-of-age movie titled "The Graduate". In this movie, the memorable line of career advice from a friend of the family to the young college graduate, played by Dustin Hoffman, was "I just want to say one word, just one word … plastics" [2]. That advice reflected the rapid growth and development of the plastics industry at that time. To name one example, Jon M. Huntsman became president of a joint venture making egg packages in 1967, a large firm with annual sales of approximately ten billion dollars today [3]. The family has a celebrated son in Jon M. Huntsman, Jr. who served as Governor of Utah and is currently serving as the U.S. Ambassador to the People's Republic of China. Plastics may no longer be the single word embodying the greatest career opportunity, but several generations of other hyped up careers have cycled through Silicon Valley since that 1967 movie, and more hype will certainly follow.

Although Silicon Valley conjures an image in the mind's eye about the electronics industry, it is best to explain what we mean by "electronics" and "Silicon Valley". The twentieth century might rightly be called the "century of electronics". The vacuum tube was invented in Palo Alto in 1906. This invention led to the development and growth of radio products. Radio, in turn, led to the invention of radar (such as at Varian Associates) and of television. The invention of the transistor in 1947 by John Bardeen and Walter Brittain permitted miniaturization of electronics products. In 1958, Jack Kilby invented the integrated circuit at Texas Instruments. However, it was the planar process (on silicon) invented by Jean Hoerni at Fairchild Semiconductor in 1959 that would permit the development of the low cost, high reliability integrated circuit (IC) at Fairchild [6]. The integrated circuit is at the heart of modern digital electronics. The name Silicon Valley was introduced by the journalist Don Hoefler in 1971 to reflect the growth of industry after the invention of the IC. As the last paragraph describes, explosive growth of IC based electronics and of the plastics industry were occurring at the same time.

When we think of electronics, we think of a dizzying set of types of devices. One simplifying definition is to think of electronics as the "four C's". The four C's are components, communications, control and computation [7]. All modern electronics can be lumped into these four categories. For example, a cell phone is a communications device. A personal computer may be a communication device, a computation device and a control device, depending on its user. A component is a part, such as an IC, that is used in an assembly such as a cell phone, a personal computer or the battery in a cell phone. A computer is made up of subassemblies such as a power supply, a keyboard or a display [11].

Plastics are created from low cost raw materials. In fact, many common plastics are byproducts from distillation of raw petroleum. Eighty percent of each barrel of oil yields gasoline, diesel and aviation fuel [4], but a portion of the remainder is used for plastics. Most plastics are filled with 68-80 wt% inorganic and organic materials to ease manufacturing, improve properties in applications such added tolerance for the ultraviolet portion of sunlight, changing the coefficient of thermal expansion (CTE) to be closer to the CTE of mating parts, changing the color, increasing thermal conductivity or modifying dielectric properties. Some plastics are as strong as some grades of aluminum but are lighter than aluminum. In any case, raw plastic stock is easy to manufacture into useful shapes. Plastic surfaces or parts for electronics applications are fabricated by a wide variety of manufacturing processes including coating, lay up, potting, extruding and many versions of molding operations (including: injection molding, transfer molding and compression molding).

Types of plastics

Plastics are composed of polymers, long organic compounds composed of a repeating chemical structure, termed the "repeat unit". These chains pack and assemble into a morphology based on the attraction, repulsion, or chemical bonding of repeat units on the same chain and between chains. Polymers are commonly categorized based on the response of these morphological changes at elevated temperatures. The two major classes important in electronics are: thermoplastics and thermosets. Thermoplastics (e.g., high impact polystyrene) are composed of polymer chains which are organized based on through space interactions of the chemical moieties on the chains. As diagrammed in Figure 1, upon heating the morphology reorganizes and the plastic can be remolded into a new shape. In contrast, in a thermoset (e.g., epoxy), chains are chemically bonded into a three dimensional network which will not flow upon the application of heat. At elevated temperature the polymer must degrade before it flows into a new shape [25].

Examples of plastics, used in personal consumer electronics, include: integrated circuit (IC) package molding compound, integrated circuit package underfill, thermal insulation, shock isolation and damping, high voltage isolation, printed wiring boards, flexible long-life interconnects for disk drives, electronics housings, living hinges, wire insulation, liquid crystal displays, lenses, optical coupling, keyboard and button springs, thermal interface material (TIM), battery electrolyte, light emitting diodes, electronic component housings, assembled module potting or encapsulation, speaker membranes, adhesives, sealants, lubricants and even the final product shipping containers. Clearly, these applications require many different material choices.

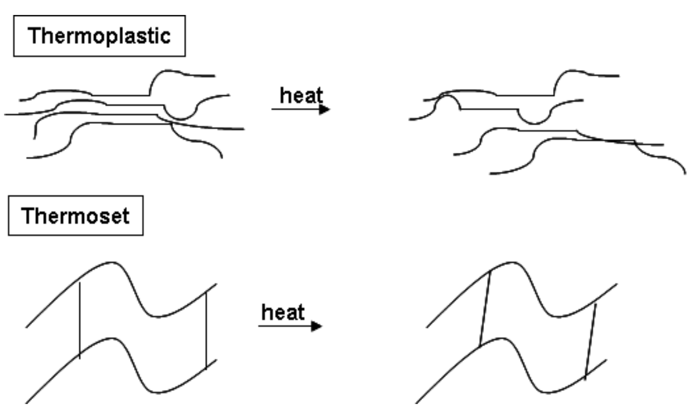
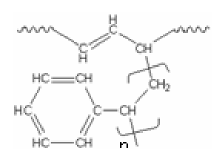
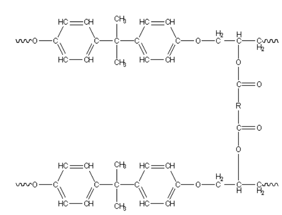
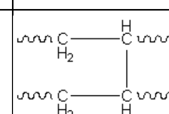
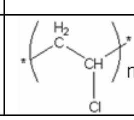


Figure 1: Sketch depicting the effect of heat on molecular chains in thermoplastics and thermosets

For the sake of simplicity, only a few plastics and applications will be discussed in this article. Currently, there are new developing uses of plastic electronic components in displays and lighting; this will be left to a future paper. The polymers which are the topic of this discussion are described and illustrated in Table 1. We will discuss the highest weight percent use of themoplastics (e.g., high impact polystyrene), arguably the highest engineered thermoset (e.g., epoxy), the most common layered use of a thermoset (e.g., crosslinked polyethylene) and thermoplastic (e.g., polyvinylchloride) in electronic assemblies.

The popular green movement has influenced the consumer's requirements for electronic products [16]. All applications of polymeric components listed above are affected by these new "green" attitudes. Consumers are now interested in electronics assembled with polymeric materials that are environmentally friendly or recyclable. Consequentially, material engineers must now balance cost considerations, engineering requirements, and end of life recycling options when designing plastics.

Table 1. Common thermoplastics and themosets components for electronics [29, 30]

Plastic	**Acronym**	**Most Common Electronic Uses**	**Classification**	**Chemical Representation**
High Impact Polystyrene	HIPS	Housings for televisions and radios	Thermoplastic-Elastomer[1]	
Epoxy	N/A	Print wiring boards and ICs	Thermoset	
Crosslinked Polyethylene	XLPE	Wire insulation	Thermoset	
Polyvinylchloride	PVC	Wire sheaths	Thermoplastic	

[1] HIPS is composed of polystyrene, a thermoplastic, and polybutadiene, an elastomer. HIPS is categorized as a thermoplastic-elastomer. A thermoplastic elastomer can be processed like a thermoplastic but has material properties that resemble that of an elastomer. An elastomer is a polymer category defined by a cross-linked morphology that is rubbery at ambient temperature and decomposes at elevated temperatures before flowing.

Environmental Impacts on Plastic Housings

Plastic housings are used to protect the motherboard and electrical circuits from environmental elements. They are the first layer of interface with the human user and include plastic shells used on electronics, such as televisions, printers, computers and telephones. Unlike other areas of the assembly, the housings must have both functional performance and aesthetic appeal. It is this consumer appeal that has driven the materials selection for this application. Wood was used to encase the electronics in the age of radios. These wood veneers added weight and cost to the electronics with limited color and decor options for the consumer. As processing of plastics became more efficient in the late 40s, they became a competitive alternative to wood. At this time housings for radios and televisions switched to thermosets, the more developed plastic class. By the early 70s, the flexibility of processing of thermoplastics made high impact polystyrene (HIPS) the favored material for electronic housings. Today, based on weight, thermoplastics are the largest plastic component in electronic manufacturing. As such, they remain under the highest level of consumer and environmental scrutiny [28].

There is a sweeping environmental political movement, generating laws that require changes in materials, including plastics. The driving public concern is possible pollution caused by disposal of electronics waste in landfills (typical in the United States) or by incineration (typical in Europe). In addition, legislation spearheaded by the environmental movement has impacted material choices for electronics packaging materials beginning with the passage of the Restriction of Certain Hazardous Substances in Electrical and Electronic Material (RoHS) by the European Union in 2003 [14]. Fire retardants and some plastics are under scrutiny by environmentalists. Specifically, any organic molecule which contains a chlorine or bromine is under consideration for removal from the electronics' assembly. Until recently, brominated flame retardants were the common compound added to plastic formulations to prevent material ignition at extreme operational temperatures. Brominated flame retardants were favored due to their efficacy at flame retardation, strong compatibility with the plastic matrix and optimal reactivity at the ignition temperature of most plastics. Fire retardants can make up to ~15 wt% of the plastic, which is generally incinerated in order to extract precious metals from the electronics [16]. Halogen containing molecules created during disposal are believed to be toxic to human health and a deleterious environmental contaminate when they are released from plastic waste.

To understand the impact of the electronic waste streams in the US, the Minnesota Office of Environmental Services initiated an electronics collection survey in 1999. During the study, used electronics from local households were collected over a three month period. The largest accumulation of electronics was televisions, which have an average lifetime of 2-3 years. High impact polystyrene (HIPS) is the most common plastic used for television housings, making up 82% of the total plastic weight [23]. Although the material used for the housing can vary based on the manufacturer, HIPS is popular for its low cost and ease in processing. HIPS has higher impact strength than most thermoplastics increasing the survival of the electronic when it is dropped. HIPS is difficult to recycle due to its low scrap value resulting from its light weight. Therefore, its decomposition characteristics in landfills have been fully characterized. HIPS does not readily undergo photolysis reactions to breakdown the plastic: once it is in the environment, it is known to linger in the water and air for decades [31]. There has been intense interest to find a plastic resin that has a smaller carbon footprint.

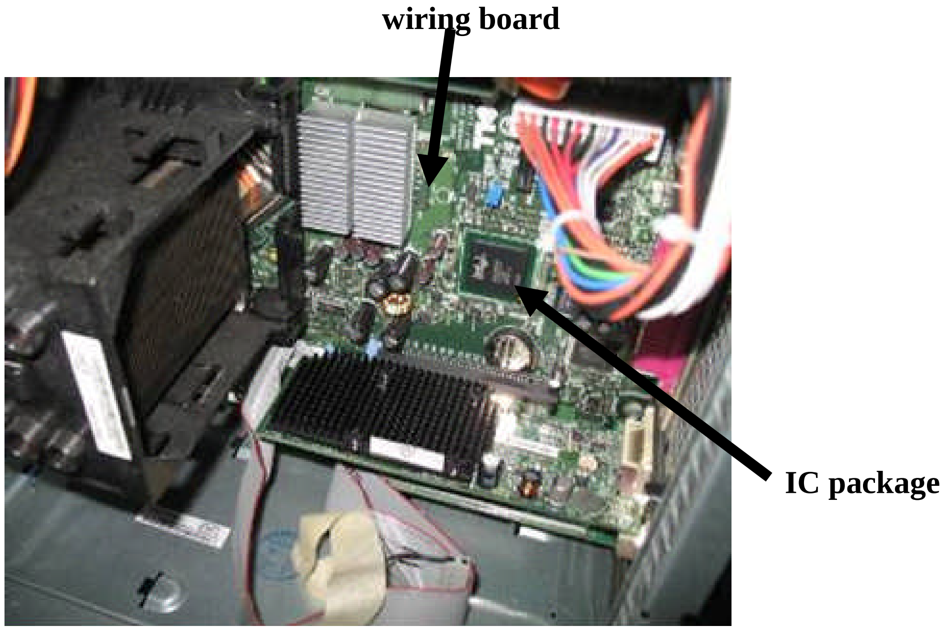


Figure 2. Desktop personal computer showing an IC package attached to a printed wiring board (PWB)

<u>IC Packaging</u>

Integrated circuits (IC) are silicon chips composed of millions of transistors, resistors and capacitors. The integrated circuits in computers are classified by function and include memory, audio and logic control among others [9]. Packaging of ICs provides protection from environmental corrosion due to moisture and oxygen. The construction and design of the package allows for mechanical and electrical connection to the next level of assembly, the oriented wiring board. The die packages typically make up a small percentage by weight of the plastics used in personal electronics; however, they are one of the best examples of the electronics industry interest in tuning plastic properties to meet stringent functional and reliability requirements.

This need for IC packaging has driven the industry through an evolution, and that evolution is continuing today. In order to explain the current challenges, some understanding of the history of packaging technology is necessary. Early semiconductor products were introduced in the 1950s. These single transistors were typically packaged in cylindrical metal cans called the transistor outline (TO) package. These metals cans provided a gas tight seal (hermiticity) for high reliability. Lower cost devices were produced molded in epoxy, with lower reliability than was required for most applications. As integrated circuits (ICs) were introduced in the 1960s, ICs were typically packaged in ceramic packages (or molded epoxy packages) such as the dual in-line package (DIP). These packages were interconnected to circuit components by mounting the packages on planar boards using tin-lead eutectic solder. The metal package leads extended through the board for mechanical integrity and were soldered on the side opposite the package. This common mounting method was called through-hole. As integrated circuit technology

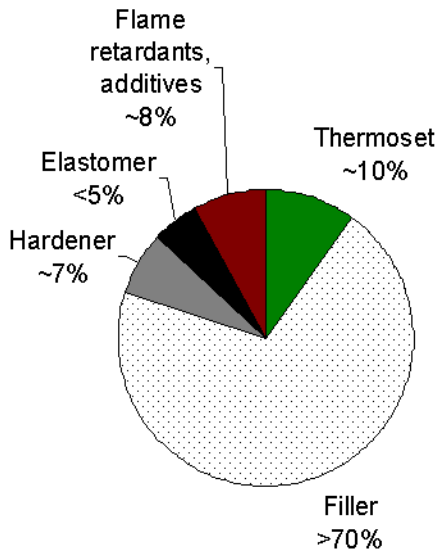


Figure 3. The composition of encapsulants made from thermosets (such as epoxy) [10]

advanced, higher functionality ICs required more input-output (I/O) electrical pins per IC package than a practical sized DIP could provide. A bewildering number of package types were invented to achieve higher I/O. As part of this drive to higher density, the electronics industry invented surface-mount technology (SMT) in which pins did not penetrate the mounting board. Surface mount IC packages included fine-pitch perimeter leaded packages with compliant leads such as the ball grid array (BGA), the flip chip and chip on board packages. SMT plastic packages became the mainstay in the 1990s with the worldwide use of cell phones, and more so, personal computing and the Internet [17].

For all the advantages provided by plastics, their use creates some issues. Compared to metal or glass, all plastics are permeable to a variety of contaminates, the most important of which is moisture. When moisture enters the plastic, it swells. In some cases, an encapsulated component can burst open like a popcorn kernel when soldered to the wiring board. There has been intense industrial effort to create standards that provide methods to work around this moisture issue. Also, there is a continuing effort to improve formulations with better properties [13]. A typical formulation for epoxy encapsulants used in IC packaging is illustrated in Figure 3; organic flame retardants compose ~ 8% of the formulation [12]. Brominated flame retardants create strong acids (e.g., hydrogen bromide) during IC processing. These acids are considered impurities in the formulation. In the presence of humidity, as moisture penetrates the packages, it carries these acids to the surface of the IC chips. Once in the presence of the bare metal, corrosion occurs, decreasing the operation life of the IC [27]. Therefore, new, ideal plastic formulations would be impermeable to water and contain acid scavengers or no latent acids. In addition to these engineering challenges, like the trends for plastic housings, there is widespread interest in the removal of these halogenated additives from the formulation. Therefore, materials engineers have focused on the replacement of organic flame retardants with inorganic substitutes for the next generation electronics.

Wire Insulation and Sheaths

Electric wiring is the simplest item used to connect components or subassemblies in electronics. All electronic components (hookup wire, connectors, printed wiring boards and integrated circuit components) are constructed with metallic conductors. Since metals exposed to the atmosphere are prone to corrosion [20], electronic product reliability is partially determined by the rate of corrosion [19]. Therefore, the electronics industry has developed packaging surrounding conductors to mitigate exposure to moisture. As pictured in Figure 3, there are multiple layers surrounding the conductor. Specific to this discussion are the plastic insulation and the jacket.

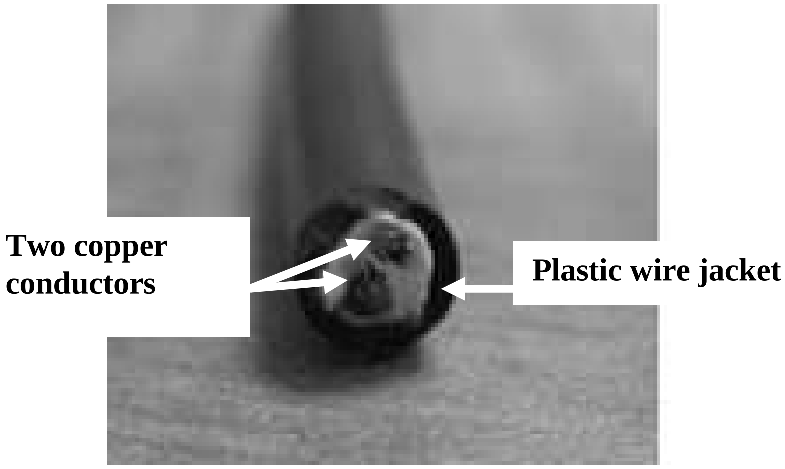


Figure 4. Wire construction

The insulation must be nonconductive, requiring a low dielectric constant and higher resistivity than the metal conductor [33]. The primary function of the plastic coating on a wire is to provide electrical isolation, to prevent leakage current and to avoid dielectric breakdown. However, the insulation must provide some mechanical features. The coating must not be too stiff and must permit flexure during assembly without compromise to its insulating properties. Given these requirements, electrical insulation is commonly composed of crosslinked polyethylene. Like encapsulants, the polyethylene is permeable to water and ionic impurities. These impurities form microscopic trails in the presence of an electrical bias, termed “water trees”. These are paths for electric current to travel from the conductor to the surrounding environment [32]. This failure mode is known to reduce the expected lifetime of most cables. However, polyethylene is a commodity polymer synthesized from the distillate products of crude oil; as such, its low cost and superior mechanical strength, when crosslinked, makes it a popular choice for electronic manufacturers. As with plastic formulations for IC encapsulation, there is research into finding more stable plastic formulations impermeable to moisture and free of ionic impurities.

The wire jacket’s primary purpose is to protect the underlying insulation from environmental elements. The material must be impermeable to atmospheric contaminants, resistant to temperature extremes expected over the product life cycle and reasonably resistant to abrasion during consumer use. In order to accomplish all these goals at low cost, polyvinylchloride (PVC) has been the most common plastic used for hookup wire [22]. Even though PVC was invented in the late nineteenth century, its patent and commercialization occurred through BF Goodrich in the early 1930’s. It was during the Second World War that PVC’s production escalated for use as electrical jackets [26]. PVC has been favored in this application due to its processability, long shelf life, resistance to environmental agents and self extinguishing behavior. However, the chlorine incorporated into the plastic structure forms toxic halogenated compounds during extreme processing temperatures and combustion. Typically, during the wire extrusion process, small quantities of PVC decomposes into hydrochloric acid. When wires are used at elevated temperatures, these acids migrate into the insulation causing localized degradation in areas where metal impurities deposit during extrusion. The localized areas of polymer degradation are visualized as small brown spots in the insulation layer; however, they compromise the mechanical integrity and dielectric properties of the insulation allowing for electrical arcing. Upon combustion, hydrochloric acid can fume from the polymer and create a health hazard. Recognizing this health concern, for years, the US Navy has forbidden the use of PVC electrical wires on their fleet in order to mitigate risk to crew in the event of onboard fires [24]. The resulting negative public perception toward PVC is slowly starting to change the mindset for material selection of commercial electronics worldwide.

Conclusion

The purpose of this article is to introduce students, or anyone who is a fan of electronics, to the bigger picture of the heart of electronics technology. The press in Silicon Valley too often trivializes technology, making it appear to be some kind of marketing and financial game, some kind of nonsense about fashionable clothing or other facets of popular culture or current politics. In fact, technology is our defining human enterprise.

Parents and teachers, and those still young at heart, should drive children to the Computer History Museum in Mountain View to see the development of electronics through the twentieth century. This short paper provides a pair of glasses through which to view the development of electronics technology. Our lenses focus on plastics to build the four C’s of electronics. The museum already clearly steps through the development of the microprocessor and the development of software, but these technologies are only a part of the story of electronics. It is our hope that this short article on plastics shows that human technological efforts are intertwined in many disciplines. Without modern plastics, electronics would still be bulky short-lived commercial devices, some of which your museum docent may be able to show you.

As with all technology, we humans modify our environment through our technology. This environmental impact is amplified as the economic benefits permit our human population to continue to explode across the globe. Therefore, our modern technologists have begun to look at our impact on the environment. We are transitioning to a view of technology that includes stewardship, much as a farmer must rotate his crops to protect the future of his land. Our article touches upon some of these environmental happenings.

As it is our hope that this article is useful to students and teachers, the senior author would like to confess that much more of modern technology was introduced in high school than he was sufficiently mature to appreciate. Teachers and students must not be intimidated by modern electronics technology. It is fair to offer that the SVEC and member societies can provide experts to help teachers step over the complexities to share the emotions of wonder and excitement of discovery.

Too often people think of silicon as the key to modern electronics, but there would be no modern electronics without other wonder materials, like plastics.

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Green Buildings and Energy Efficiency

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What is a green building and why is it important? Are green buildings a marketing gimmick or a real solution to the challenges of the current built environment? This article provides a brief over view of green buildings. It elaborates on standards, technological, and economic trends in green buildings and energy efficiency. We conclude that green buildings are a powerful means to create a sustainable built environment, and reduce the pressure on natural resources. Green buildings will become the default due to increasing regulatory frameworks that require energy consumption data for real estate transactions closure and proactive energy management.

Keywords: green building, energy efficiency, LEED® Rating System

Introduction: Green Buildings and their Importance

A green building is one that has a minimal impact on the earth, atmosphere and biodiversity; provides superior indoor environmental quality; uses water and energy efficiently; utilizes sustainable materials, and minimizes waste generation during construction and occupancy. A common misconception is that green buildings are only possible in new construction. Contrary to that belief, any building can be made green through energy/water efficiency, waste/purchasing policy changes and operations & maintenance best practices.

Energy efficiency is an essential element of green buildings. Green buildings optimize the use of energy and water through appropriate design of engineering systems, climate responsive features, and on site renewable generation. Energy efficiency is therefore critical to a high performance green building. In the US, energy efficiency is getting greater attention than green buildings for two reasons. First, the existing building portfolio is much bigger than the new building portfolio and has a higher energy saving potential than new building. Second, the current economic downturn has made financing for new building development scarce.

Architecture always reflects a period's response to socio-political-economic conditions and technological advances—Gothic, Renaissance, Moghul, International Style, De-construction are examples to name a few. Climate change, globalized economy and ever increasing pressure on resources are some of the challenges of our times. Green building and sustainable cities, therefore, are an important and integral part of a resource constrained global economy. Businesses, real estate industry and end users are slowly acknowledging the merits of high performance green buildings as critical solutions for the low carbon economy. Green buildings are on the verge of becoming the new architectural style of the 21st century.

Emerging Standards

LEED® Rating System

The green building movement has picked up steam and vigor around the world. US Green Building Council (USGBC), a nonprofit organization, pioneered a green rating system, Leadership in Energy and Environmental Design (LEED) in the US [1]. LEED Rating system evaluates and credits a building project on measures related to Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, and Innovation in Design. LEED certification works on a point system to create a total rating. Projects are awarded Platinum, Gold, Silver rating based on how many points they achieve for various green measures. The family of LEED certification includes LEED NC for New Construction, LEED EB for Existing Buildings, LEED CI for Commercial Interiors and many more. The LEED rating system witnessed tremendous growth in the last five years in the US. LEED rating has developed a following in Canada and Asia as well. Similarly modeled rating systems have been developed in Europe, Australia and other commonwealth countries. An example of a silicon valley green building is San Jose City Hall (designed and built as a green building by Richard Meier & Partners) that applied for LEED EB certification after it was constructed and successfully occupied [2].

Sustainable design practices are not a new concept to the architectural design community but the market readiness and brand image of green buildings is new. The noteworthy aspect of LEED rating system is the strategy used by USGBC for its proliferation. For centuries, architects designed projects worthy of their environmental appeal. For example, Frank Lloyd Wright designed "Taliesin West" in Scottsdale, Arizona and "Falling Water" in Pennsylvania as architectures that complemented the natural landscape and local materials [3]. Laurie Baker, a UK-trained Architect who settled in India, designed buildings that responded to local climate and resources [4]. There were no market-based incentives for large-scale adoption of sustainable building design elements. What USGBC initiated was a multipronged marketing strategy for widespread adoption. USGBC created a green building momentum through new products (such as low mercury lamps), professional consensus-based changes to the rating system, and a common platform for materials certification (such as the Carpet and Rug Institute for low volatile organic compounds (VOC) carpets). Additionally, the LEED rating system targeted many building types such as commercial buildings (new and existing), schools, and hospitals—thereby increasing the total market size and penetration. The multipronged strategy pushed the green agenda for buildings forward.

Green Building Code

The merits of green buildings and government push for energy efficiency has increased the popularity of the LEED Rating System in the US. For the last few years, USGBC has launched a parallel effort on public policy lobbying with the states, municipalities, and cities for adoption of components of the LEED rating system in building codes. Many cities have incorporated elements of the LEED rating system into their green building code. A very diverse community of design consultants, institutions, government bodies, building owners/operators, and real estate industry now accept the value of LEED Rating System in developing green building.

Building Energy Performance Disclosure

Significant standard development is happening in building energy efficiency as it relates to energy performance disclosure. Energy performance disclosure means disclosing how a building operates and uses energy. Energy policy leading states such as California will require energy performance disclosure for real estate transactions starting next year. Other states may also follow the trend. Forward thinking European economies have implemented energy labeling for buildings associated in real estate transactions [5]. This trend establishes the importance of constructing energy efficient buildings and retrofitting poor performing buildings with efficient technology. At least one international standards body (ASTM) is developing a new standard to provide a methodology for the collection and disclosure of energy use information [6]. New regulatory standards will provide market based incentives for building owners to invest in green building and energy efficient retrofits. For a building to operate efficiently, owners also need to institute continuous energy management.

Technology and Economic Trends

Green building is a rapidly evolving sector. On the technology side, an emerging trend is convergence of building and information technology sectors. The buildings retrofit market is a multibillion dollar untapped market [7]. There is scope for technologies and services that bring new methods, and tools to make existing buildings more energy efficient. Several startups and established companies are developing information technology (IT) based solutions that increase efficiency and save energy in lighting, space heating and cooling, and building controls.

Data centers are one of the fastest growing building types in the US [8]. Data center growth is driven by several factors, such as the global nature of companies and the need for business software applications and computing power on the web. Data centers are buildings that house data computing machines. A paradigm shift is occurring in corporate buildings with data center growth. US-based multinationals are consolidating their office footprint and expanding data center footprint in US and abroad. Incorporating sustainable design practices in data center construction is another big wave in green buildings. Currently, USGBC’s LEED Rating system does not have a dedicated certification type for data centers. In the future, USGBC might have to develop a new certification type exclusively for data centers.

On the economic side, green building/energy efficiency offers both opportunities and challenges. There is growth opportunity for businesses that make products and solutions for new and old buildings. At the same time there are financial challenges due to the current economic crisis. For private sector and big corporations there are challenges for capital investment due to tight credit financing and pressures from shareholders. Federal incentives are being directed to stimulate investment in renewable energy such as solar, geothermal and wind as well as energy efficiency retrofits in buildings. Incentives programs offered by local utilities and tax rebates/cash grants from the federal government also offer some help.

The Future of Buildings

The global economic downturn has constrained the development and financing of green buildings temporarily. When the market picks up, demand for green buildings in developing economies and retrofit of existing buildings in developed economies will rise. Energy efficient green buildings will become the de-facto standard internationally. There will be global growth opportunities for emerging energy efficiency technologies. There will be no geographic barriers in adoption of new technologies because we live in a connected global market. New technologies will permeate global markets through cost efficiencies. For example, solar water heaters have become ubiquitous in developing economies such as China and India.

Evolving standards, regulatory changes and technological advances make one wonder about the future direction of buildings. In the carbon-constrained economy of the future, buildings might even become an asset with energy and carbon bar code.

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Structured Innovation &The Inventor's Mindset

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Some say Silicon Valley's (SV) environment is what makes it unique. But with highly-educated low-wage competitors around the world duplicating SV's environment and best practices, the Valley's differentiation is slowly eroding. Without an important edge, jobs and R&D will continue to be outsourced.

Innovation is today's stated differentiator. This paper introduces research about innovation and explains how invention can be a structured process. This structured process is evolving into an applied science. Critical components of Structured Innovation are discussed including: Psychological Inertia, Ideality, and Secondary Problems. Also examined are valuable inventors' characteristics such as Responsibility, Problem-Solving Courage & Persistence that enable breakthroughs.

Structured Innovation is an emerging science with a comprehensive set of approaches to difficult or "impossible-to-solve" problems. This discipline creates new differentiation in a dynamic and competitive business landscape for SV leaders.

Key words: Structured Innovation, Psychological Inertia, Ideality, TRIZ, Altshuller, Kuhn

Introduction

Silicon Valley (SV) engineers have all the reasons in the world to be confident in their technical and inventive abilities. For decades, technically-excellent engineers improved products, materials, and processes and commercialized them. Since competition is tough in the Valley, engineers must be high-caliber to succeed.

So why write a technical paper on innovation for Silicon Valley engineers?

<u>REASON ONE:</u> For approximately 200,000 years, humans have believed innovation occurs like a lightning-strike of brilliance. The general beliefs and experiences are: 1) a person must passively wait for breakthrough ideas to hit and cannot take direct control of the creative process; 2) any person lucky enough to receive a significant idea must grab the most benefit possible because lightning-strikes of brilliance may never reoccur; 3) finally, serial innovators[1] and inventive geniuses are rare talents. All these ideas are wrong.

> *"If you can't describe what you are doing as a process, you don't know what you're doing." W. Edwards Deming*

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[1] Our first exposure to the term 'serial innovator' was via Bill Pine in a 2003 Applied Innovation Alliance (AIA) presentation called "The Next Big Thing". Bill Pine coined and described the term and it was used in presentations extensively for two years. The phrase "serial innovators" still appears in copyrighted presentations of AIA. Around the same time, CHI Research published a paper called "Small Serial Innovators: The small firm contribution to technical change" released in 2003 suggests that Leigh Buchanan of INC Magazine coined that term.

REASON TWO: Sociologists and behaviorists have studied the Silicon Valley environment. This information has long since been disseminated, and people all over the world learned ‘how to create an environment that supports innovation’. Therefore, little islands of duplicate Silicon Valleys are popping up in India, Route 128, Austin, and Seattle; Italy is attempting to be the world’s foremost software innovators, Germany the solar innovators, Scotland, China, Brazil have all learned enough to establish their own ‘Silicon Forest’, ‘Silicon Glen’, ‘Nanotech Middle Kingdom’, ‘Biotech Desert’, etc. All around the globe people are vigorously copying The Silicon Valley Environment in an attempt to build their area/state/country into the new global leader of innovation.

> *Silicon Valley is the only place on Earth not trying to figure out how to become Silicon Valley. Robert Metcalfe*[2]

Silicon Valley businesses face unprecedented competitive pressure from around the world. It is only logical to conclude that if we continue to do what we’ve always done and others are doing it now as well, the whole world will get the same results. Silicon Valley’s “innovation” differentiator is eroding.

> *It wasn't that Microsoft was so brilliant or clever in copying the Mac, it's that the Mac was a sitting duck for 10 years. That's Apple's problem: Their differentiation evaporated. Steve Jobs*

This paper intends to introduce Silicon Valley leaders to research that reveals a new understanding about innovation. Despite a natural tendency to resist the unfamiliar, innovation has quietly been evolving into a structured and scientific discipline. This new paradigm is much more useful and effective than “waiting for a lightning strike” (REASON ONE). Some basic innovation principles are discussed so Silicon Valley engineers and up-and-coming business leaders can begin the difficult journey of adopting a new mindset in order to retain their inventive leadership and take innovation to the next level of evolution and differentiation (REASON TWO).

A New Innovation Paradigm & “The Structure of Scientific Revolutions”[3]

A New Innovation Paradigm Called Structured Innovation

Many myths about innovation exist today. Probably these myths are largely unchanged from the time the first humans created them in an attempt to explain the seeming unpredictable nature of the innovation process. Sixty years ago, all that changed.

Genrich Saulovich Altshuller is responsible for the beginning of the innovation paradigm shift. Altshuller clerked in a Russian patent office and like other notable patent examiners and clerks before him (e.g., Thomas Jefferson, Clara Barton, and Albert Einstein), Altshuller was a

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[2] Robert Metcalfe, InfoWorld, March 2, 1998

[3] Thomas S. Kuhn (1996), *The Structure of Scientific Revolutions*. Third edition, University of Chicago Press: Chicago, IL and London.

prominent thinker. His specialty was thinking about innovation. He noticed there were patterns of invention and that intrigued him.

> *"I became more and more interested in the mechanics of creativity. How were inventions made? What happens in the head of the inventor?"* [4] *Genrich Altshuller*

Altshuller developed generic rules that explained the patterns he observed in patentable ideas and unique creations. This method gained popularity in the Soviet Union since they did not have the same financial prowess as the United States for R&D. The Soviet Union had to fight the Cold War and Race-to-Space with mental tools and the occasional computer.

Altshuller devoted his life to understanding innovation and organizing the collected research into a body of work now known as TRIZ (*Teoriya Resheniya Izobreatatelskikh Zadatch)* - in English this is translated approximately as the *Theory of Solving Inventive Problems*. He was especially interested in making TRIZ systematic, teachable, and scientific. In 1974, that brand of TRIZ came to North America.[5]

Since then, the study of the-process-of-innovation has grown at the confluence of many hard and soft sciences: psychology, neurology, mathematics, tool development, best practices, sociology, philosophy, leadership, physiology, metrics development, business practices, history, decision analysis, and much more.

Structured Innovation is the integration of TRIZ plus other methodologies and sciences including strategic planning and competitive intelligence. In a nutshell, Structured Innovation is a practical and a proven discipline, well on its way to becoming an applied science. And yet, it has remained mostly underground. Why?

Thomas S. Kuhn & the Structure of Scientific Revolutions

Humans are comfortable with our current ideas and feel safe adhering to an existing paradigm. We want our scientific theories to evolve from linear, factual accumulations of proven truths and incremental improvements.

Thomas S. Kuhn states that "science develops during periods of stable growth punctuated by revisionary revolutions." He says "the development of a science is not uniform but has alternating 'normal' and 'revolutionary' (or 'extraordinary') phases. The revolutionary phases are not merely periods of accelerated progress, but differ qualitatively from normal science."[6]

Up until about 1945, our ideas about innovation had evolved using Kuhn's definition of the normal phase and were carried by the momentum of thousands of years of belief. Any

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[4] Genrich Altshuller (H. Altov) (1992-1996), *And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving*. Technical Innovation Center; ISBN # 0964074028.

[5] Lev Shulyak brought TRIZ to America in 1974. Another wave of TRIZ scientists came to America in 1991 after perestroika. TRIZ began to impact the American business marketplace in the early 1990s.

[6] Bird, A., Stanford Encyclopedia of Philosophy (Aug 13, 2004), "Thomas Kuhn", available http://plato.stanford.edu/entries/thomas-kuhn/. Last accessed on November 21, 2009.

improvements, made to the paradigm in this normal phase were incremental; thus, our comfort was undisturbed. The paradigm remained largely unchanged. Then something extraordinary (revolutionary) happened (Altshuller's work), and this major paradigm revision clarified our understanding of innovation.

Kuhn went on to claim that the normal phase of scientific development makes progress when there is "a strong commitment by the relevant scientific community to their shared theoretical beliefs, values, instruments and techniques, and even metaphysics"[7] - a shared paradigm. When inconsistencies arise within this shared paradigm, corrections may be incorporated if they are performed in an incremental, empirical, linear fashion.

The established 'normal' innovation paradigm is based on millennia of observations. It was observed that innovation happened unpredictably. Innovation lightning-strikes were attributed to the gods, to nature, to hubris, to luck, to many things. As the paradigm evolved, the relevant scientific/social community concluded innovation is simply unpredictable and unknowable since the innovation process occurs largely inside the mind and therefore leaves few visible clues. Thus, the accumulated knowledge about inventiveness (from the old paradigm) is still quite primitive.

Kuhn claimed that, as a general rule, humans don't like change unless the current paradigm ceases to work. Once common science can no longer predict future outcomes and conditions or when problems arise that cannot be explained, or when anomalies become too obvious to overlook, then a global crisis in confidence takes place and a new paradigm finds a voice. This new paradigm, if accepted, completely replaces the old truths. This is the 'extraordinary' phase of science (revolutionary, non-linear).

Those who study inventiveness have noted many anomalies within the old innovation paradigm. For example, occasionally a genius inventor appeared - one who could reliably and serially innovate important breakthroughs when needed. This anomaly in the lightning-strike theory was explained away (e.g., something within the environment enabled great, repeatable innovation; or this genius is one of natural selection's rare gifts to humankind). The inconsistency was glossed over because it did not fit with the general consensus - the "constellation of shared commitments"[8] - the presiding paradigm. Even when Thomas Alva Edison wrote to peers about some of his methods for stimulating innovation, historians titled them "tricks" and concentrated their writings about how unique and important Edison was. In this way, history reinforced the prevailing (lightning-strike) paradigm and added to the myth that only the rare and gifted few could serially innovate.

For Genrich Altshuller, the anomalies were too obvious to ignore; they could not be explained away.

> *Although people who had achieved a great deal in science and technology talked of the inscrutability of creativity, I was not convinced and disbelieved them*

[7] Ibid.

[8] Thomas S. Kuhn (1996), *The Structure of Scientific Revolutions*. Third edition, University of Chicago Press: Chicago, IL and London, pages 10 – 22 and pages 181 - 187.

> *immediately and without argument. Why should everything but creativity be open to scrutiny? What kind of process can this be which unlike all others is not subject to control?…What can be more alluring than the discovery of the nature of talented thought and converting this thinking from occasional and fleeting flashes into a powerful and controllable fire of knowledge.*[9] *Genrich Altshuller*

The more he learned, the more developed Altshuller's ideas became. Finally, a revolutionary new paradigm was introduced: innovation could be systematic. The process could be taught, and learned.

However, as stated previously, non-linear development has a tendency to make people uncomfortable, even when the new paradigm is more useful than the old. Humans resist change for different reasons.

- Even when the new paradigm is heard, understood and makes sense, most people do not accept it right away; they wait and see what others think about it first;
- Or they accept it, in theory, but refuse to incorporate it because they do not see how the new paradigm will make their daily life better;
- It takes too much effort to make the change and learn the 'new way' and there are too many other things that require attention until competition forces the effort.
- If there is no change, personal power structures as well as strategies, workloads, and knowledge bases remain static. No new learning is required. No change equals no loss of prestige or fear of criticism for not seeing the new way. The benefits achieved through social consensus in the old paradigm remain in place if nothing changes.

So, despite the overwhelming evidence that a revisionary revolution in innovation is under way, most of today's successful business leaders, scientists and engineers will resist (and are resisting) or will ignore the changes, even when the benefits are highly compelling.

Although Altshuller's (and his team's) early work was a revisionary revolution of the old innovation paradigm (according to Kuhn's definition), the new paradigm's adoption seems to be following the typical marketing diffusion-of-innovation pattern.[10] The science of innovation is evolving in both a non-linear and linear fashion.[11]

As shown in Fig. 1, diffusion is the process by which an innovation is typically communicated through certain channels over time among members of the scientific/social system.[12] This process is complicated because many disparate sciences and disciplines make up Structured Innovation.

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[9] G.S. Altshuller (1984), *Creativity as an Exact Science*: *The Theory of the Solution of Inventive Problems*. Gordon and Breach Science Publishers Inc. (Fourth Printing 1998)

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[12] Rogers, Everett (December 10, 1997), *Diffusion of Innovations Theory*. Paper linked to http://a.parsons.edu/~limam240/thesis/documents/Diffusion_of_Innovations.pdf

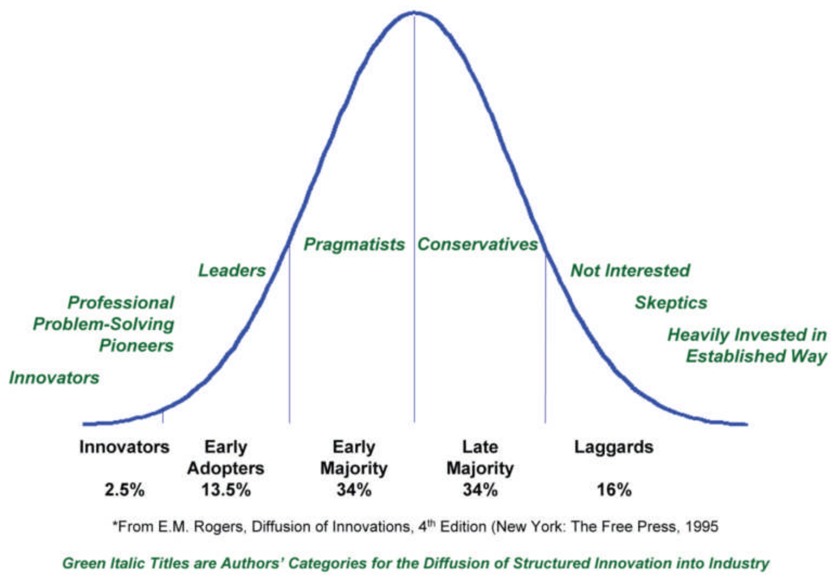

Fig. 1 Diffusion of Structured Innovation into Industry

Based on the authors' estimation, the adoption of the new paradigm is currently in the Early Adopters phase.

Early Adopters are paradigm alpha- and beta-testers. They research the ideas, examine the concepts within the current system and look for new constraints; they test, apply the theories, make note of, explore, and talk about the new paradigm. Misunderstandings are recognized, clarified and explanations are evolved. New ideas and expansions are developed, tested, corrected, and re-applied. Limits are stretched. It can be a chaotic but also invigorating process.

Finally, full understanding of how the new paradigm applies to the marketplace is achieved and the early adopters begin to succeed in ways the old paradigm can no longer ignore. More and more adopters pay attention. Eventually a tipping point is reached. The old paradigm is superseded by the new rival, which then diffuses throughout the mainstream. Many innovator-companies are achieving success and early adopters are beginning to implement innovation as a core competency within their companies.[13]

While it is difficult to tell who is adopting the new innovation paradigm most rapidly, trends indicate significant countries and important competitors - Iran, South Korea, Taiwan, India and

[13] Innovator Companies: BAE Systems, Computer Sciences Corporation, Proctor and Gamble, Ford Motor Company, Boeing, Daimler Benz, Chrysler, Phillips Semiconductors, Samsung, LG Electronics, General Dynamics Land Systems, Xerox, IBM, Hewlett Packard, and others have reported success using TRIZ or Structured Innovation to solve complex technical, scientific and organizational problems. Innovator company data derived from web-based research and from Hubenthal Burr Associates, LLC client successes and innovation alliance members; http://en.wikipedia.org/wiki/TRIZ; http://www.businessweek.com/innovate/content/may2006/id20060531_965895.htm

Japan - have a high level of interest in the topic and are active in its use.[14] If Silicon Valley engineers and business leaders are to retain the innovation differentiator they currently enjoy and benefit from, we recommend taking an early adopter mindset. Visionary captains of Silicon Valley, including the current crop of upcoming leaders, need to be examining questions similar to the following:

- Do we have a map of potential game-changing breakthroughs that we use to navigate our business into the future?
- As a venture capitalist, am I waiting until an idea presents itself or am I able to map the many potential future technologies that are worth investment? Can I recruit talent that can generate invention when it is needed? Can I find inventive talent for business model development or for legal strategies?
- As a business leader, am I skilled at new product creation but stumped at strategic business model creation? Or vice versa. Am I focused on operational excellence at the expense of innovation? Do I believe the two are mutually exclusive?
- How does a breakthrough occur in my area of expertise? What specifically happens in the minds of my innovators?
- My engineers may have an impressive list of patents, but can they teach the skill to others? And can they reliably invent on-demand if they are assigned to create a breakthrough?
    - Are the improvements inventive-level breakthroughs or only incremental?
- Do I have structured training methods so my company's key stakeholders can be taught to innovate? Does my company use a team-based innovation process? Are we utilizing the expertise of the various teams & their interactions?
- Do we calculate the ROI of issue resolution without also considering the cost of not solving the problem (especially if the competition is trying to solve it)?
- Are we relying on individual performances and lightning-strikes of brilliance (the traditional process) rather than a more systematic approach? Do we know by job function how innovation applies to someone's job? Do we have a comprehensive strategy for implementing innovation company-wide?
- Are our teams at odds with each other (e.g., marketing versus engineering)?
- Do we face technical or business process obstacles that seem impossible to solve?

These questions and others like them reveal knowledge gaps that have not been fully addressed, understood or resolved by the old paradigm.

> *...it doesn't matter how beautiful your theory is, it doesn't matter how smart you are - if it doesn't agree with experiment it's wrong. Richard P. Feynman, Nobel Prize winning Physicist*

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[14] Based on research from Applied Innovation Alliance presented to the Society of American Military Engineers: on November 18, 2009, Cincinnati, Ohio, *Using Structured Innovation to Invent and Prevent Catastrophic Events:* According to Google Trends, these countries search for "TRIZ" the most: http://google.com/trends?q=TRIZ; Iran is likely using TRIZ for their strategic actions against the USA; South Korea ranked second among 110 countries in the global innovation index measuring business outcomes of innovation and governments' ability to encourage and support innovation through public policy, according to the Boston Consulting Group (BCG); the others use TRIZ for business competitiveness.

The new paradigm, however, can fully address these questions. Structured Innovation brings hands-on, real-life clarity and great insight to the business landscape. The new innovation (problem-solving) process consistently delivers effective solutions. An effective innovation paradigm based on science will create needed insight and differentiation.

Authors' Conventions

This paper refers to a person using one or more of the essential underlying structured innovation principles as an "innovator" or "professional innovator" or "professional problem-solver". Various methods, practices, and processes comprise the structured innovation system. When all of those 'tools' are mentioned en masse, the authors refer to "the Structured Innovation toolset" or the "Structured Innovation system".

However, it is seldom necessary to make use of the full toolset to create a breakthrough. Most innovations can be achieved using a small selection of "tools"; therefore, when the authors reference a part of the system, we will call out that principle, section, tool, or process by name and explain it in detail.

<u>Behavioral Study Approach</u>

The authors are members of an innovation-based consortium/alliance dedicated to the advancement of American innovation. The members work on individual and joint research and development projects. Information is collected through case studies, on-the-job participation (shadowed and observed), trainings & coaching & mentoring, correlated data sharing, interviews, meetings, and multi-disciplinary research.

Studied members are both female and male and range from expert serial inventors to novices. Ages range from high school students to age 75. Multiple industries are represented.

Interview questions are generally contextual. The observation process includes shadowing participants performing their day-to-day activities or in actual team problem-solving sessions. In addition, observing members were invited to meetings/events the subjects were leading or participating in.

Reoccurring themes are discussed by the authors and sometimes with alliance members. During these sessions, validation and verification gives feedback, develops theories, and makes changes as needed. No formal report has been compiled as yet.

Structured Innovation Overview

In a nutshell, Structured Innovation is a scientific approach to problem-solving.

Structured Innovation is particularly useful at smoothing a path so innovators can solve difficult or seemingly 'impossible-to-solve' problems in an accelerated timeframe.

Humans solve problems all the time. When the answers come easily, are obvious, and flow to us, the Structured Innovation toolset is not necessary. But when problems are tough or complex, when we are stuck and no solution is in sight, when we are at the edge of what is currently known, or when we need a breakthrough, this is when Structured Innovation is useful.

Sometimes a good answer does arrive in a flash - like a lightning-strike of brilliance. But if no flash of brilliance is forthcoming, humans typically look externally for answers. Often this externally found advice does not consider the many constraints and problems that are unique to the specific situation; however, looking externally for answers is the most comfortable and common solution.

- We use the experience of those who are in similar conditions and succeeding.
- We look for new experts, new research, and best practices.
- We continue to do what always worked in the past, despite varying conditions.
- We use historical references to emulate successes from similar circumstances in the past.

If we take the same actions as everyone else, the best we can hope for is achieving the same results as everyone else. If, however, Silicon Valley engineers and business captains wish to retain inventive leadership, they need to understand what the mass of others do not yet grasp.
It is now known that when solving inventive-level problems (whether they come in a flash or from a structured approach) the human brain goes through a series of procedural steps. Some of us do it so quickly, we are completely unaware of our own mental processes - but the important point here is that we have a strategy and process. All of us do it; we do it every time we solve tough problems. And because this ‘strategy and process’ has been studied for decades[15], innovation has become structured, as odd as that seems.

> *You can wait a hundred years for enlightenment, or you can solve the problem in fifteen minutes with these principles. Genrich Altshuller*

Here is an analogy. Archimedes developed the first procedures of calculus in the third century BC. But Archimedes was killed before he could teach his procedural steps to others and although he wrote about his theories, his writings were lost.[16] It was centuries before his work was re-invented. This loss-of-calculus is analogous to how difficult it has been to understand inventive genius. For thousands of years inventive geniuses solved tough problems using unarticulated techniques. Humans watched in awe from the sidelines because the genius’s hidden mental processes and strategies were not assessable by external observation.

In the 1700s, both Isaac Newton and Gottfried Wilhelm von Leibniz re-invented calculus. At first only a small group of individuals could understand and use this new math because much of what these innovators did remained in their heads. However, once Newton and von Leibniz wrote down and disseminated their work, their ideas were understood, scrutinized, tested, and rigorously applied (diffused throughout the relevant scientific and social community). Today, high school students routinely learn and use calculus because it has been structured over the centuries and students can be taught the step-by-step procedures.

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[15] Genrich Altshuller’s first technical book was written in 1961, *How to learn to Invent*. The basic ideas in this book are (A) you do not need to be born an inventor and (B) it is ridiculous to use the trial and error method of discovery. Altshuller is the founder of TRIZ.

[16] *The Archimedes Codex: How a Medieval Prayer Book Is Revealing the True Genius of Antiquity's Greatest Scientist* (Hardcover) by Reviel Netz (Author), William Noel (Author)

Just so, the procedural steps - the strategies and the processes of innovation - have been researched, developed, scrutinized, tested, and rigorously applied during the past sixty years. This method can be taught – even to high school students.

Genrich Altshuller studied over 200,000 patents before concluding that there were about 1,500 technical contradictions that could be resolved relatively easily by applying 40 fundamental principles of invention. Over the decades, much of the science of innovation has been devoted to chronicling and exploring the procedural steps so they can be taught to others, for example[17]:

- What steps do great leaders take and how do inventors think?
- What steps happen first?
- What kinds of problems are routinely solved?
- How do systems evolve?
- What is the essence of all great inventions?
- What types of risks are commonly overlooked?
- and more.

Now that innovation is a procedure and a discipline, it is more predictable[18] in producing effective solutions than the lightning-strike approach - just as calculus has made it easier to solve a broad class of mathematical problems. Today, much is known about the procedural steps of innovation. In this paper, the authors will discuss only a part (indicated with an asterisk) of the basic Structured Innovation Toolset below:

- Psychological Inertia *
- The Four-Step Innovation Process
- Ideality *
- Resource Utilization
- Secondary Problems *
- Characteristics of the Inventor *
- Contradictions
- Separation Principles
- System Approach
- Other Topics

And, like calculus, most people can be taught to use the methodology - it doesn't matter if you are a right-brain or left-brain thinker. As shown in Fig. 2, the ideal practitioner of the methodology possesses deep competence and comprehensive experience in at least one field of study (e.g. music, engineering, physics, biology, computer science or anthropology, etc.) and has surface knowledge or an interest in many subjects.

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[17] Genrich Altshuller (H.Altov) (1992-1996), *And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving*. Technical Innovation Center; ISBN # 0964074028. Translated by Lev Shulyak

[18] Based on the authors' experience and research and the experience of others in the profession; as a science, structured innovation remains in the early stages of its evolutionary arc. It is effective in producing a positive outcome but not necessarily a "predictable" outcome.

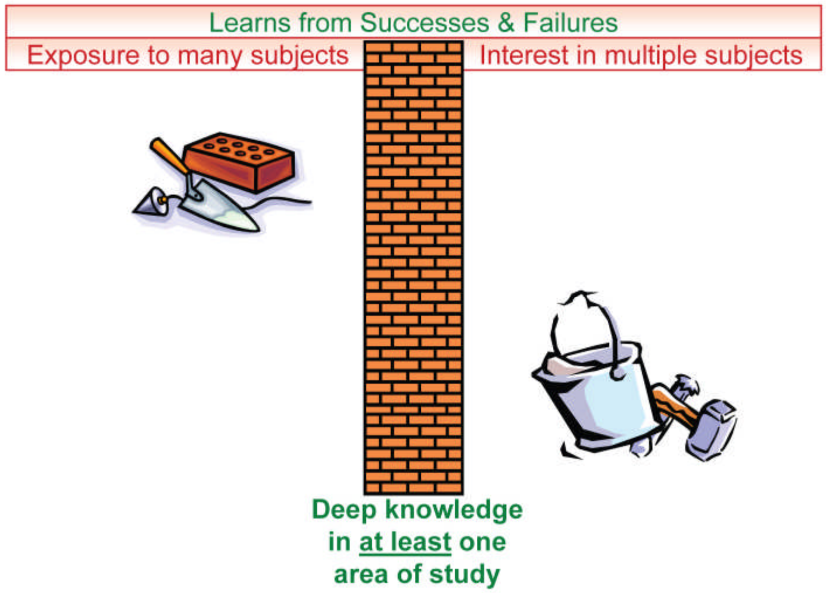

Fig. 2 Most Innovators Have Knowledge Similar to a "T"

Both individuals and teams can use the process effectively, which is useful since modern problems often require a multidisciplinary team-based approach and non-linear thinking as well as an ability to shift points of view to solve a problem.

Because tough problems can be resolved more reliably in the new paradigm and innovation skills can be taught (learning innovation skills is similar to learning math skills), some managers are tracking innovation within their company. They quantify the costs of solving a particular problem, or of not solving it.

In fact, some early-adopter companies assign "Innovation Specialists". This term usually refers to a small team or an individual trained in innovation skills. They are typically budgeted under corporate (or a business unit, directorate, etc.) and assigned to problem-solve hot spots within the company. The innovation experts work with subject matter experts and together they step through the innovation method to resolve issues. This method achieves two benefits: first, the problem is solved and the solution is implemented; second, the innovation methodology is disseminated naturally throughout the organization. Once management understands the full impact a system of innovation can have if the workforce was trained in it, they usually move to develop inventiveness as a core competency with the company (from management on down the hierarchical ladder starting with key stakeholders or influential leaders).

Within innovator/early-adopter businesses with a company-wide core competency, problem-solving is scheduled, tracked, quantified, and managed - just like other key business processes: cost reduction, quality optimization, inventory turns, or supply chain management, new product development and/or customer-focused development, etc. Companies, like Dow Chemical, have integrated the innovation process (in the form of TRIZ) as a scientific discipline and achieved advantages within their organization.[19]

In order to develop innovation as a procedural core competency, devotees must acquire the understanding, discipline and skill - just like devotees of calculus must study and develop disciplines and skills. The following three sections detail foundational requirements of systematic innovation.

Psychological Inertia[20]

One of the primary objectives of the Structured Innovation system is to overcome *psychological inertia*[21], which is the tendency to continue to think and behave as we have always thought and behaved. The use of the term "inertia" carries the full implications of Newton's inertia as applied to mindset, psychology and social dynamics.

Inertia, of course, is the tendency of a body to maintain its state of uniform motion (or rest) unless acted upon by an external force. Objects have inertia. What many leaders do not to realize (and do not effectively leverage) is that companies and individuals have inertia, too. The secret of success is to know when *psychological inertia* is beneficial and when it begins to harm.

For example, if management sets a company direction for being first-to-market (e.g., Procter & Gamble, Cisco Systems) and rewards employees when they bring products to market quickly, then the company strengthens around that concept and it is easier to continue moving the company in that direction - that is inertia.

Within a first-to-market company, the mergers & acquisition team receives accolades and is well rewarded when finding a complementary technology that produces big market wins. In a first-to-market company, technical directors who deliver quick, reliable development of high-priority projects also benefit.

Ironically, over time, management may realize the first-to-market mindset causes problems. Acquired companies, for example, may not integrate well. Some newly acquired key employees cause trouble. Some leave and some "just blend into the woodwork" and stop producing. Documentation and product design processes are chaotic or non-existent. A lot of money is lost or left on the table. Employees in low visibility areas feel undervalued. These are indicators that company-wide inertia has crossed-over from beneficial culture to harmful effects.

This is the point where management typically reacts. They look around to see what other companies are doing, what new information is available, and what industry's best practices are.

[19] Podcast: *"What is TRIZ and How can You Pair it with Six Sigma?"* Tom Kling, Master Black Belt, Dow Chemical Company, with Host, Genna Weiss. http://www.sixsigmaiq.com/podcenter.cfm?externalid=13

[20] This section and other sections of this paper are based on the concepts and writing previously published in "A New Competitive Strategy for Insurance Industry Leaders", by Dayna Hubenthal and Scott Burr, HBA Asset C677466, Copyright 2008 Hubenthal Burr Associates

[21] 'Psychological inertia' is a TRIZ technical term defined by Genrich Altshuller.

Management will readily find examples of businesses with strong process-centric cultures and those businesses appear, at first glance, to hold the missing keys. Such businesses advocate almost opposite behaviors (because they have strong *psychological inertia* along their own lines and see only their own success but do not fully understand their own problems and how that will influence this different situation[22]).

If these process-centric experts are to be believed, adoption of new tools, systems, and initiatives will solve all of the problems grown in the first-to-market culture. Therefore, management may impose initiatives company-wide (for example, Six Sigma, Lean, CPI). The new directive requires workers to significantly change habits, but there is too much momentum and inertia from the previous way. This new directive is not 'native' or natural to the first-to-market culture. Employees do not believe the resolve behind the dictates; they are afraid for their established positions and anticipate the loss of understanding of how to work the system; they resist. In order for the initiative to survive, great external force is required - consistently applied over time. In today's business world, the odds are in favor that management will give up before employee resistance is overcome. At the very least, change will not occur overnight - that is inertia, too.

As a general rule, directives passed down "from on-high" do not work when resistance is great. When initiatives fail, leaders need to address the psychological inertia within the company in a methodical, structured manner. Yes, systematic innovation can be applied to change management (social/cultural) problems as well as technical issues.

> *Inability to overcome psychological inertia, in its many forms, is at the root of every failed company initiative. Scott Burr*

Individuals, as well as companies, develop mindset momentum. We humans are adept at finding patterns that win. We like to use success patterns over and over again, repeating the familiar. Producing predictable results makes us feel skilled and our peers view us as skilled, too. On an individual level, inertia is satisfying.

Inertia becomes problematic when we use old patterns over and over again, repeating the familiar, but are no longer producing the results we desire. That is when inertia crosses over into stagnation. At this point, the most important skill is the ability to examine our inertia.

This, then, is one of the primary skills and disciplines of the inventor. The innovator constantly self-examines personal mindset and the inertia (prevailing mindsets) within the system/situation. This great skill sets breakthrough-problem-solvers apart from the rest of the engineers, scientists and leaders.

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[22] The classic comments made by management and countered by consultants have truth in both perspectives: Management often says, "My business is different," while consultants espouse. "Our toolset will solve your problems….with a change in mindset." How true this is from both sides of the coin. The real heart of the issue is to understand what psychological inertia is worth changing and what is worth keeping. The productive conversation should revolve around what is important to the company moving forward without looking to compromise. From this standpoint, both viewpoints are relevant and productive, management sets direction for values they want to retain while productively leveraging the consultant to address the fundamental issues at hand. Management's "ideality" is pursued in this process, eschewing a trade-off mentality.

Thomas Kuhn discussed a similar dynamic when explaining the effects of a shared paradigm. He said that in order for normal science to make progress there must be a strong "constellation of shared commitments" or a "disciplinary matrix"[23] (psychological inertia). "An inculcation of that commitment is a key element in scientific training and in the formation of the mind-set of a successful scientist. This tension between the desire for innovation and the necessary conservativeness of most scientists was the subject of one of Kuhn's first essays in the theory of science, "The Essential Tension" (1959)."[24] In many respects, Kuhn's *essential tensio*n is strongly related to Structured Innovation's *psychological inertia*.

Engineers and leaders often fail when they must confront their 'essential tension' or recognize psychological inertia has crossed over into harm. The reason for the blindness is because the most problematic inertia is derived from the foundational skills, knowledge, and experience a business or a reputation is built upon.

Examples of this type of inertia are demonstrated by start-ups that fail to thrive as well as big companies who do not respond to disruptive innovations.[25] This is also the classic scenario Kuhn describes in the resistance to scientific discoveries, called anomalies, which negatively affects the reputations of established scientific leadership but is also rightfully part of the vetting process for good science.[26] Therefore, it is difficult for leaders to believe these particular bits of inertia are even open for question. Psychological inertia that has crossed over into stagnation is often our personal 'truth' and 'fact' and seems justifiable.

All functional knowledge can contain problematic momentum.

Once problems start appearing, especially tough or complex problems with no obvious solutions, then all knowledge needs to be examined, especially the knowledge that is universally accepted. With new knowledge being generated at an unprecedented rate in history, old knowledge can quickly become obsolete. This trend will only accelerate over time.[27]

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[23] Thomas S. Kuhn (1996), *The Structure of Scientific Revolutions*. Third edition, University of Chicago Press: Chicago, IL and London, pages 10 – 22 and pages 181 - 187.

[24] Thomas S. Kuhn (1959), *The Essential Tension: Tradition and Innovation in Scientific Research,* The Third (1959) University of Utah Research Conference on the Identification of Scientific Talent, edited by C. Taylor, Salt Lake City: University of Utah Press: 162-174.

[25] (A) Geoff T. Huang (11/7/2008), "*Why startups fail: A Top 10 List From Geoff Entress, Seattle's Prolific Angel Investor,*" - Reason number seven: Founder's don't change their business model when it becomes obvious that it is flawed. http://www.xconomy.com/seattle/2008/11/07/why-startups-fail-a-top-10-list-from-geoff-entress-seattles-prolific-angel-investor/. Last Accessed 12/13/2009. (B) Clayton Christensen: "Because companies tend to innovate faster than their customers' lives change, most organizations eventually end up producing products or services that are too good, too expensive, and too inconvenient for many customers. By only pursuing 'sustaining innovations' that perpetuate what has historically helped them succeed, companies unwittingly open the door to 'disruptive innovations'." http://www.claytonchristensen.com/disruptive_innovation.html

[26] Thomas S. Kuhn (1996), *The Structure of Scientific Revolutions*. Third edition, University of Chicago Press: Chicago, IL and London, pages 61 – 65 and page 151.

[27] Scott Burr, *"Ten Global Trends and the Role of Innovation in your Future"* Presentation to American Society of Mechanical Engineers, 2009 Student Leadership Seminar, Richland, WA. (A) Source: How Much Information? 2003 (B) Hubenthal Burr Associates, LLC estimate: new knowledge is doubling every decade.

Since new understandings create new possibilities, inflexible companies or engineers then can quickly become obsolete or irrelevant. Successful technologists must take stock of their current functional knowledge and its associated momentum (inertia) [28] since several bodies of knowledge may be obsolesced during a well-managed career.[29]

Psychological inertia may develop due to:

- Decisions
- Precedents
- Traditions
- Habits
- Standards
- History
- Ability to fit-in
- Culture
- Assumptions
- Problem statements
- Scientific knowledge
- Facts
- Truth
- Law
- Beliefs
- Creeds
- Hunches
- Intuition
- Opinions (popular or not)
- Outlooks
- Etc.

Looking at it from a different point-of-view, today change is occurring at an unprecedented rate. When a situation shifts (and it always does), we have fewer options available. The moment 'an option' becomes 'a fact' and when we no longer challenge this fact, we become vulnerable to the encroaching effects of change. Irrelevance begins when we do not adjust.

Aluminum molds for production injection molding or short stroke die sets with small diameter guide pins, for example, could have occurred up to thirty years earlier (they appeared in general use in the 1980s) as no limitations existed in materials or process. [30] The only barriers were in mindset. These examples illustrate how reliance on assumptions and unexamined facts (opinions that have proven useful over time) can lull traditional leaders into "psychological corners" they are too comfortable to think their way out of.

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[28] *The Measurement of Scientific and Technological Activities,* Oslo Manual Guidelines for Collecting and Interpreting Innovation Data, 3rd Edition, Page 11, Pages 31 -33

[29] Scott Burr, *"Ten Global Trends and the Role of Innovation in your Future"* Presentation to American Society of Mechanical Engineers, 2009 Student Leadership Seminar, Richland, WA. Sample technologies and knowledge bases rendered irrelevant or obsolete: cordwood module was replaced by PC Board, Slide rule was replaced by the calculator, Drafting was replaced by Computer Aided Design, Typewriter was replaced by Word Processing, the CRT was replaced by the LCD, Standalone computing replaced by Networked Computing, Hand assembly replaced by Automation, etc.

[30] Early in his career (~ 1988), Scott Burr designed a short stroke die set based 0.5 inch diameter guide pins and 0.75 inch plates. The company's machine shop supervisor refused to build the die set since it did not conform to standard design practice (long stroke, 1.5 inch plates, 1.5 inch guide pins were standard) and it challenged the supervisor's 30 years of experience and it eschewed die set industry traditions. Scott stood his ground. The die set was soundly engineered. The machine shop supervisor demanded the VP of Engineering fire Scott for incompetence. The die set was made and proved these decisions were sound (actually conservative) based on stated requirements. The die set delivered performance beyond documented expectations and reduced the cost of the die set by several thousand dollars. This example demonstrates how difficult it is to overcome psychological inertia even in ordinary and justifiable situations. Today 0.25 inch guide pins are routinely used for short stroke die sets.

Fig. 3 The Current Paradigm Shows us the Edge of What is Known

Innovators, on the other hand, do not get stuck in corners because when they access historical experience or well-honed skills or education to solve problems, they question the validity of those assumptions.

Many people think that the environment surrounding us is the source of our problems. From this point-of-view, if we change the environment, we can eliminate our problems. However, there are always problems within our landscape because there always will be more to understand. Despite great effort, problems will always plague us. That is not going to change. As shown in Fig. 3, the current paradigm shows us the edge of what is known. What can change is our resignation-to-fate, which is a form of psychological inertia. Now this is important: *we are affected by external issues only because the situation we nurtured has made us vulnerable to them*. External constraints do not equal impingement. It is not a direct correlation.

For example, a recession does not exactly correlate to business impairment. Hewlett Packard was established during The Great Depression as was Birds Eye Frozen Foods. Disney was a start-up during the 1923-4 recession; Microsoft began during the 1975 recession. Whole new industries were born within the crucible of crisis: the film industry, radio and modern marketing.

The reason some companies gain competitive advantage during times of great constraint is because this is exactly when most people are stuck in psychological inertia. Their experience, education and skills have driven them into a corner they cannot think their way out of and their support system - the experts, everyone - agrees that the external situation impinges, thereby calcifying a 'fact' into a paradigm that does not serve.

Those who win advantage when the environment is severe are those who have the most relevant mindset - a mindset focused on proper preparation and innovative responses.

> *"Man must cease attributing his problems to his environment, and learn again to exercise his will - his personal responsibility." Albert Einstein*

Once we realize that external problems impinge upon us because our mindsets have made us vulnerable to those particular problems, a re-tooled mindset enables us to predict market upheavals - and recover more creatively and intelligently to external impingement. Great external pressures can be opportunity waiting to happen.

One of the professional innovator's foundational tools is the desire to take responsibly for promoting clarity within a situation. The innovator does this because it is known that poor mindsets cause paradigm limitations and restrict breakthroughs. Constantly, the innovator monitors dearly-held beliefs to make sure the correct goals are supported. Often the most powerful drivers within a system are the unquestioned facts and tacit assumptions underlying a situation.[31] Most people do not want to put in the necessary work to continuously clarify a situation, much less question which facts are true and which "facts" are habits. Unquestioned beliefs require energy to overcome. Since our mindset (*psychological inertia*) is responsible for our problems, clarity requires effort but it also helps ensure our mindset remains relevant. Acquiring this kind of clarity is valuable beyond estimation when solving difficult problems.

It is doubtful that American business leaders are managing their mindsets. According to the 2008 survey taken by the at Harvard's Kennedy School Center for Public Leadership, 80% of the American people believe we have a leadership crisis in the country today. Overall confidence in leaders fell sharply over last year. Confidence in business leaders dropped further than any other sector.[32]

Business leaders fail to inspire confidence when they take the easy path instead of deeply considering their choices and the effects their choices will have in the greater community, whereas great leaders know their influence and understand the mindset that helped create the problems within their systems.

Look at it slightly different: leaders must cease looking for external solutions *at the expense of looking internally*. Here's a harsh example. General Motors is constantly looking externally for new tools and ideas to help them out of their hole. The authors know good people employed at General Motors. These employees diligently work to make things better, but we can see it's not getting much better. Even if General Motors survives, they are losing market relevance. The problem is their *internal* landscape is too constricted by psychological inertia. Applying new tools within the context of their unexamined tunnel vision has led (and will continue to lead) to mediocre results at best.

Leaders at General Motors, and indeed, all American companies and Silicon Valley businesses, must begin the extremely uncomfortable process of questioning the very things that make them valuable. The more leaders practice, the more adept they will become at understanding their own mindset and the mindset that creates their situations. They become more valuable as a leader and

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[31] (A) Edgar H. Schein, *Organizational Culture and Leadership*, Jossey-Bass, 2004
(B) Level Playing Field Institute and Center for Survey Research and Analysis at the University of Connecticut (2003) [1] The HOW-FAIR study 2003: How opportunities in the workplace and fairness affect intergroup relations. Level Playing Field Institute, San Francisco.

[32] Harvard Kennedy School, Center for Public Leadership, National Leadership Index 2008
http://content.ksg.harvard.edu/leadership/images/CPLpdf/nli%20report.pdf, pages 1, 3

to the community when they understand the undercurrents of their systems. The mindset of management, of individuals, and of teams are a valuable corporate asset (note the authors are not referencing optimism, job satisfaction, happiness or even morale).

Self-limiting comments professional innovators often hear people within the old paradigm say:

- "This is the way it's always been done"
- "If it ain't broke, don't fix it"
- "Why not, it's always worked before?"
- "Who is to blame for this?"
- "It's against the laws of physics" [33]
- "How much can we afford to implement?"
- "That won't work"
- "You can't have it all"
- "Who else is doing that?"

These comments are made as if precedent will guarantee future success or as if precedent holds the best solution.

> *Learning is not compulsory... neither is survival. W. Edwards Deming*

The worst of psychological inertia is when social norms evolve to support limited and fixed paradigms – a structure that involves blind belief without examination. Humans spend a lot of time and effort convincing others that their limited point-of-view is the only worthwhile and necessary viewpoint (both implicitly through social norms and explicitly through persuasion and influence). Thus, the dominant, observable behaviors reinforce themselves.[34] Participants in a limited mindset seek solace in common experience (a self-reinforcing downward spiral). Below is advice from two different leaders to counteract this downward spiral:

> *The significant problems we have cannot be solved at the same level of thinking with which we created them. Albert Einstein*

> *We need to do more than fix the crisis; we need to fix the mindset that got us into it… We cannot solve problems of this magnitude simply by replacing today's leaders with people who think and act just like them.[35] Harvard Professor, Bill George (in a recent article)*

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[33] This statement, in particular, is a sign of psychological inertia. It clearly indicates that the wrong physical laws are being used to try and solve the problem. Take Moore's law as an example (in which the number of transistors that can be placed inexpensively on an integrated circuit has doubled approximately every two years) and how it had been routinely predicted in the science press that the laws of physics would not support the next generation of line width reduction only to have a new breakthrough making it possible to continue.

[34] The dominant behaviors are reinforced through "Pluralistic Ignorance". It is largely because individuals assume the most memorable and salient, often extreme, behavior is representative of the behavior of the majority. This may lead individuals to adjust their behavior to that of the presumed majority by adhering to the pseudo-norms created by observing such memorable behavior. These exaggerated perceptions, or rather misperceptions, of peer behavior will continue to influence the habits of the majority, if they are unchallenged. http://en.wikipedia.org/wiki/Social_norms_approach; http://en.wikipedia.org/wiki/Social_norm;

[35] Failed Leadership Caused the Financial Crisis, U.S. News and World Report website posting, 11/19/2008; http://www.usnews.com/articles/opinion/2008/11/19/failed-leadership-caused-the-financial-crisis.html

Let us examine psychological inertia from a different perspective. Innovators know that a mindset is not who you are, it is just what you think. This is a subtle but important concept.

Very often the reason people cannot change their thinking and get stuck is because they identify with their thoughts. In other words, people generally weave their identity from the strands of what they think, whereas, innovators realize 'thoughts' are just powerful tools. What we think repeatedly, gains momentum in our lives; but these ideas can still be challenged as necessary.

Who we are - our identity - comes from our internal moral compass (our core integrity) and stable biological brain processes.[36] The origin of our thoughts, however, is a different matter. Our thoughts come from our identity, our beliefs, our experiences, our education, our observations, our environment and community influences. While we often believe our thoughts represent our identity, nothing can be further from the truth. The thoughts we think may be absolutely incorrect even if they feel true.[37]

Identity may be steadfast, but thoughts need to be pliable so we can make constant improvements to changing conditions. In this manner we can adjust what and how we think with finer and more refined understanding of the reality we face.

Thoughts congeal when we identify with them, forming the basis and structure for future thinking. Those thoughts, when repeated, solidify into 'fact' in our lives. When this happens, we block ourselves from the possibilities based on alternative points-of-view and reduce flexibility in our thinking.

When problems seem too tough or complex to solve or when whole industries face the same problem, it is because people have over-identified with thoughts and those thoughts transformed into unquestioned beliefs and solidified 'truths.

> *Do not rely upon repeated hearing or rumor, written words or axioms, the authority of knowledgeable teachers and elders, or the traditions that have been handed down. Instead use observation and analysis and verify that it agrees with reason and is not harmful but beneficial to all. Once this has been done, then accept the principles taught to you by others. Gautama Buddha*

<u>In Summary of Psychological Inertia:</u>
An innovator's basic skill is to recognize when psychological inertia is a barrier. The discipline of constantly examining the current mindset and situation is important to creating breakthroughs. It is valuable to keep 'identity' separate from 'thoughts' and to keep thoughts pliable. Adopting a flexible and open mindset is part of an innovator's prowess.

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[36] Daniel Amen, M.D. *(1998), "Change your Brain Change your Life,"* Three Rivers Press, New York, pages 1-15.

[37] Daniel Amen, M.D. *(1998), "Change your Brain Change your Life,"* Three Rivers Press, New York, pages 55-67.

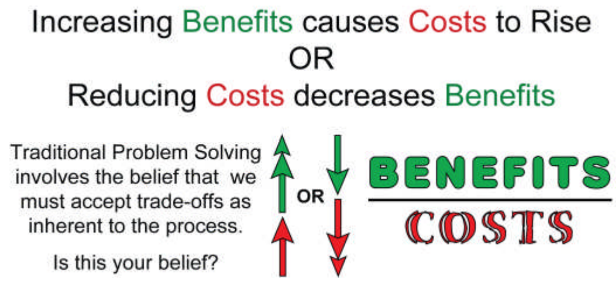

Fig. 4 Traditional Problem-Solving

Ideality versus Trade-offs
As engineers we are trained to make effective trade-offs. To do so, we use optimization tools, graphical comparisons, and statistical decision-making. Optimizing trade-off scenarios is a goal so engrained in the Silicon Valley engineering mentality, it seems incongruous to start the problem resolution process by thinking about eliminating the problem completely - with all gain; no downside.

> *If you think you can do a thing or think you can't do a thing, you're right. Henry Ford*

Ideality[38] (an ideal solution) is the first mindset a professional innovator uses to address psychological inertia. It is the opposite of a trade-off. As shown in Fig. 4, a trade-off is defined as, "appropriate improvements in one desirable parameter occur at the expense of another desirable, but less important parameter".

On the other hand, as shown in Fig. 5, the ideal solution dictates that "a solution must simultaneously deliver more of what you want AND less of what you do not want". Trade-off involves compromise whereas ideality seeks the most ideal solution and eschews the trade-off mindset.

A paradigm always occurs within a static frame of reference. Ideality holds the possibility of multiple frames of reference. The idea is to step outside of the frozen frame of reference and define the problem in relationship to a more ideal frame of reference. Changing the point-of-view often opens up possibilities. Professional innovators begin with Ideality. In a nutshell, innovative problem-solvers begin resolving issues from a different point-of-view than traditional thinkers.

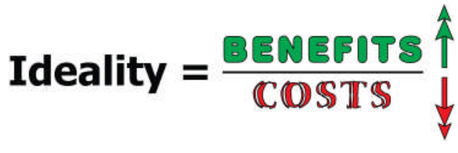

Fig. 5 Increase Benefits & Reduce Costs for Dramatic Improvements

[38] 'Ideality' is a technical term in TRIZ, defined by Genrich Altshuller in multiple ways including, "The function is performed without the existence of the system".

History is more or les bunk. Henry Ford

Traditional problem-solving starts with repeating historical precedent and with making incremental improvements and using the established mindset and linear knowledge of predecessors (Kuhn's normal science). Many managers use this predictable strategy to mitigate risks. The underlying beliefs of a traditional action plan are *reactivity* and a *trade-off* mentality. For example, a problem appears, demands attention, the engineer responds to a problem and does the best possible with resources at hand. Engineers and leaders usually default to this thinking pattern when under pressure or when asked to work in areas of their lowest competence (outside of their comfort zone).

Obstacles are those frightful things you see when you take your eyes off your goal. Henry Ford

Traditional Problem-Solving	**Structured Innovation**
• "If it ain't broke, don't fix it"	• Where is the detrimental psychological inertia in the current AS IS situation?
• When it breaks, figure out who or what is to blame?	• Research historical precedent with an eye to understanding resistance to a solution & how the situation has changed to inform adjustment.
• You can have it fast, right or cheap - pick any two - you can't have it all.	• Pursue ideality by resolving contradictory requirements so all three (better, faster & cheaper) can be realized.
• Prioritize which parts need to be fixed	• Discover how to eliminate the offending parts and make the system work without them
• Calculate how much of the solution we can afford to implement. Optimize the trade-off between costs and benefits.	• Determine what we want by asking, "How can I get more of what I want AND less of what I don't want?" Go for the Maximum Tolerable Ideality[39]
• Figure out "Who is standing in my way?" or "Who needs to get on-board?" "Who can help?" and "What's new?"	• Innovate with key stakeholders to create a robust solution (this is a natural approach to change management). Together address secondary problems; predict & solve failure before it happens.
• Work through the trade-offs, develop a plan, and then take logical, appropriate actions.	• Work through the innovation methodology taking logical, appropriate actions along the way.

[39] Maximum Tolerable Ideality: The authors' term to define the maximum level of discomfort, uncertainty and contradictory evidence willing to be tolerated in pursuing a highly desirable ideality. This is similar to Kuhn's "Essential Tension" but in an expanded sense relating to the tensions in all problem-solving. An alternate term, we sometimes use is "Ideality's Essential Tension" in honor of Kuhn's contributions to this concept.

From the onset, the subtext of a conventional problem-solving methodology is very different from the subtext of an innovative approach. The underpinnings of an action plan for innovation are *responsibility, persistence and courage*.

The Relationship of Ideality and Responsibility

Because innovators are constantly managing their mindset, innovators assume responsibility to keep tabs on (manage) the evolving situation and monitor goals and recognize signals that point to future trouble and current obstacles. The innovator is also responsible for challenging assumptions that contribute to the current AS IS situation. And the innovator is also responsible for believing a more ideal situation is possible.

This sense of continuous responsibility requires discipline and is a core problem-solving skill. NASA recently conducted a study called, "the NASA Systems Engineering Behavior Study"[40] to identify the characteristics and/or behaviors frequently observed in highly-regarded System Engineers at NASA. "Problem-solving ability" was one of the five most important behaviors identified and the characteristic of 'responsibility' was foundational to the 'problem-solving' behavior. NASA's research correlates strongly with the authors' experience.

The authors also find that ideality demands responsibility from the innovator. Below is a list of some of the important NASA characteristics:[41]

- Takes the initiative to solve the problems
    - Takes responsibility for the whole life-cycle, the whole system and all its parts
- Creates vision and direction
- Understands the whole job and that it is never done
- Understands the integrity of the system is a primary role
- Accepts responsibility for the performance of the system
- Does not assume there is only one right answer
- Remains objective so as not to be hindered by irrelevant, outside influences
- Adapts to Change and Uncertainty
    - Understands that change is inevitable and takes appropriate actions quickly
    - Moves concepts and ideas easily through artificial boundaries
    - Makes difficult or unpopular decisions, keeping the best interest of the system in mind
- Carefully monitors the impact of decisions on system performance, backtracking and changing direction if necessary.

An additional crucial characteristic for innovators is the ability to quickly learn from successes and failures that is related to accepting responsibility. [42]

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[40] Study Leads: Christine Williams, NASA HQ and Mary-Ellen Derro, JPL (October 2008), "*NASA Systems Engineering Behavior Study*"; NASA Office of the Chief Engineer; For this paper, the study was accessed December,2009 - *http://www.nasa.gov/pdf/291039main_NASA_SE_Behavior_Study_Final_11122008.pdf*

[41] Study Leads: Christine Williams, NASA HQ and Mary-Ellen Derro, JPL (October 2008), "*NASA Systems Engineering Behavior Study*"; NASA Office of the Chief Engineer; The study was accessed December, 2009 - *http://www.nasa.gov/pdf/291039main_NASA_SE_Behavior_Study_Final_11122008.pdf*; pages 9-16

No matter how tough, complex or constrained a situation is, the innovator knows a solution is possible. Innovators do not *try* to solve a problem; they do not *hope* a solution is available; they do not *think* they might solve the problem. The breakthrough thinker *knows* an ideal solution exists. This is part of managing the AS IS mindset. This is not the same as optimism. This *knowing* is a skill to be developed.

> *I am looking for a lot of men who have an infinite capacity to not know what can't be done. Henry Ford*

Belief in the Ideal Condition moves leaders beyond system psychological inertia, which makes trade-offs necessary. It is not foolish or unrealistic to believe in an ideal solution. In fact, in the Harvard Business Review, Jim Collins wrote about "Level 5 Leaders" (who transform companies from good to great) and how these leaders had a particular quality of holding two apparently contradictory beliefs in their awareness simultaneously. Collins' research claims Level 5 leaders have absolute faith that what-is-desired is possible (*ideality*) and will occur; simultaneously they face the brutal fact that the current reality contains no known path to a solution. Additionally, Level 5 Leaders have a contradictory combination of fierce resolve and humility.[43]

> *A professional innovator's mindset = (facing the current dismal reality + the unknown) x (belief in finding a solution + absolute resolve to solve the problem) = the table stakes of an effective innovator. Scott Burr and Dayna Hubenthal*

Admittedly, an ideal solution sometimes seems impossible. This is exactly when the tools of a methodical system can help achieve a breakthrough that meets real needs and creates an applied solution that sticks. Pioneers do not generally head off into the wilderness with nothing. They choose tools they know will help them succeed when they enter the unknown. Serial pioneers learn which tools are useful no matter what the environmental conditions. Structured Innovation is the toolset for going into wilderness of creating breakthrough solutions. Ideality is the mindset that creates the impetus and courage to forge ahead. Then with fierce resolve and humility one is ready to face the unknown.

Problem-Solving Courage & Persistence

In order to develop innovation as a critical core competency within a company, the effective development of individuals is vital. This development requires an understanding of the characteristics or behaviors that enable employees to be highly-effective, inventive-level problem-solvers.

The authors have studied past and present serial inventors in order to identify characteristics or behaviors frequently observed in highly-regarded problem-solvers. Data from this research plus

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[42] Learning from failure and success is expressed in an innovator's behaviors as courage and persistence. Based on the observations and experiences of the authors' successful projects and projects of peers, this led us to identify unique references in the literature on the role of persistence and courage in delivering innovation.

[43] Jim Collins (2001), *"Level 5 Leadership: The Triumph of Humility and Fierce Resolve,"* Harvard Business Publishing.

the original works of Altshuller and his teams have been used to evolve Structured Innovation and to design and update training, development, and mentoring programs.

In spite of the fact that the practice of Structured Innovation has been applied to multiple industries and for various types of problems (technical, transactional, process improvement, social/human interactions, etc.), the behaviors of high-performance, inventive-level problem-solvers are consistent. In this section we will discuss two foundational competencies innovators consistently exhibit. Innovators must have the *courage* to begin and the *persistence* to keep going until success is achieved.

The NASA Systems Engineering Behavior Study identifies specific descriptors of important behaviors which include:[44]

- Is fearless and has an authentic and persistent desire to understand how everything works and how it relates to everything else
- Possesses creativity and problem solving abilities
- Moves without boundaries from one topic to another, to discover what else needs to be known, and what might be overlooked
- Actively explores the technical issues, concepts, and lexicon of subsystem disciplines that are less familiar and comfortable
- Asks difficult questions of discipline or subsystem experts regarding boundaries, conditions, and assumptions
- Willing to speak up, regardless of who is present to ensure the most technically sound decision is made for the good of the overall system
- Exhibits confidence
- Does not adhere to rigid rules or formulas for system design, but may create new ideas and approaches that are necessary to deal successfully with system constraints.

'Next step' or 'incremental' improvements do not demand the same skill set as doing something no one else thinks is possible. Over and over, professional innovators hear, "That can't be done", "It's impossible", or "It's against the laws of physics"; and those beliefs impede breakthroughs for the non-inventor before they even begin.

In our studies, when we move a team past that initial resistance and into a more effective mindset, the next obstacle is one of the following;

- "But, what about …"
- "I don't see how we are going to approach this"
- "I don't know how we'll get the buy-in"
- "I'm not sure what the steps are;" or "I'm uncomfortable not knowing what the next steps are"
- "I can't plan for this since I have no idea how to go about it or what it will take"
- "Since I don't know ahead of time how this will end, I cannot commit resources to the process"

[44] Study Leads: Christine Williams, NASA HQ and Mary-Ellen Derro, JPL (October 2008), "*NASA Systems Engineering Behavior Study*"; NASA Office of the Chief Engineer; The study was accessed December, 2009 - *http://www.nasa.gov/pdf/291039main_NASA_SE_Behavior_Study_Final_11122008.pdf*; pages 9-16

Granted, these are valid fears. Everyone faces these obstacles, or ones similar to them, upon entering uncharted territory. But innovators do not let those fears stop them - and that is neither unrealistic nor unduly optimistic.

Inventors embrace a unique paradox: 1) face a great problem without knowing the outcome and 2) possess absolute resolve to overcome that obstacle. Great historical inventors and innovators such as Cai Lun[45] were realistic and persistent; Naomi Nakao[46] is eminently determined; both Madame C.J. Walker[47] and Elijah McCoy[48] were highly courageous yet realistic. In order to invent, you must have the persistence and the resolve to proceed while remaining practical and grounded in the current real situation.

Many competent engineers and leaders are comfortable only when a plan is laid out. They feel persistent only if the territory is familiar, or if they have previously taken analogous actions, if there is a mentor they can question, or if the procedural steps are visible and laid out for scrutiny - if the way is logical. If these conditions are met, competent engineers feel comfortable even if accomplishing the task will require hard work. As long as the way is clearly defined, traditional engineers and leaders are willing to proceed. The job appears exponentially more difficult when the way is not clear.

> *Most people spend more time and energy going around problems than in trying to solve them. Henry Ford*

Remember, when problems seem too tough or complex to solve or when whole industries face the same problem, it is because people have over-identified with established thoughts and those thoughts have transformed into unquestioned beliefs and solidified ‘truths’. So when no path currently exists, that is because of rigid beliefs which govern the limits of knowledge. To create

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[45] A servant of the Chinese imperial Han Dynasty court (sometimes spelled Ts'ai Lun) is credited with the invention and innovation of paper in 105 A.D. He took paper beyond a technical invention and helped drive its widespread adoption such that it became a successful innovation, one that would stick, dramatically changed the world. Paper Industry International Hall of Fame, www.paperhall.org/inductees/bios/2009/cai_lun.php

[46] During a 20 year journey, Dr. Nakao searched for solutions to address shortcomings in medical devices that resulted in 56+ patents. She learned a great deal about the problems that an inventor encounters. Granit Medical Innovations (GMI) was founded by Dr. Naomi Nakao in order to provide a vehicle for taking intellectual property from idea to medical device through collaborative alliances with medical equipment manufacturers, biomedical engineers, FDA advisors, and distribution channels. Dr. Nakao is Chair of the Invention Innovation Special Interest group of American Society for Gastrointestinal Endoscopy; http://www.ideafinder.com/history/inventors/nakao.htm

[47] Alelia Bundles (2008), *Madame C. J. Walker;* Chelsea House Publishers - Madame C. J. Walker was the first American woman of any race to become a self-made millionaire. She was born of former slaves, worked as a laundress with few prospects, and was poor for most of her life. She experimented for years before coming up with a line of hair-care products for Afro-American hair when she was 37 years old. Eleven years later, she owned and operated her own thriving business, the Madam C.J. Walker Manufacturing Company. She overcame great odds and did not let preconceived ideas, which were rampant in her environment, limit her success.

[48] Elijah McCoy overcame racial injustice during his life and went on to register 57 patents, including the automatic lubricating cup, which revolutionized the industrial machine industry, a folding ironing board and a lawn sprinkler. Some attribute the the saying ‘the real McCoy’, to mean ‘the real thing’ - derived from Elijah's solid inventions. http://en.wikipedia.org/wiki/Elijah_McCoy

opportunity one must regain control of their mindset. There is real opportunity for the hardy and flexible-minded person in an industry of rigid thinkers.

> *I cannot discover that anyone knows enough to say definitely what is and what is not possible. Henry Ford*

For example, the manufacturing industry typically believes capital equipment is expensive and must have an extended life and needs to be sturdy. To achieve an extended lifecycle, engineers design with durable materials (steel, aluminum, or composites) and manufacture with costly processes (e.g., precision machined parts), which increases expense. Because the equipment will produce millions of parts or improve quality or safety or productivity, the manufacturing industry justifies decisions based on a cost versus benefit analysis (costs = initial expense, set-up difficulty, difficulty to use, cost to train, etc). This is standard wisdom. It is also a trade-off, therefore, not an ideal solution.

Also, today businesses face a poor credit environment. There is also demand to build 'mass-customized' products. The situation is ripe for out-of-the-box thinking. Could the ideal new 'capital equipment' not be a fixed asset? Maybe new equipment still needs to improve quality, safety, productivity *and* be inexpensive. Maybe it needs to be easy to reconfigure and dynamically re-purposed to match changing needs *and* must be lightweight and movable with a small footprint, while being easy to learn to use. Maybe equipment will be both disposable but simultaneously last a long time. That is a contradiction that seems impossible to solve: It is the perfect opportunity for a new pliable mindset.

When conventional wisdom says the scale *must be* big, then breakthroughs are waiting for someone who can innovate the same benefits in a small package.[49] Visionary leaders examine assumptions and challenge conventional wisdom and create past the edge of what is currently believed possible. Great inventors throughout history know this secret: Invention takes vision, courage and persistence. Opportunity lies in "what is desired" but "cannot be accomplished".

Repetition builds strength. If you want to be a repeat-inventor, you need to exercise the innovation muscles and develop the supporting muscles of courage and persistence. You practice searching for ideality in your mindset, even when the way is unclear and no solution seems possible - seek the most ideal solution you can tolerate.

> *When everything seems to be going against you, remember that the airplane takes off against the wind, not with it. Henry Ford*

[49] The advantages of surface mount technology developed in Japan eliminated the need for larger components by challenging the psychological inertia that very small parts could not be handled by automation. The Japanese had no choice since floor space has a premium cost in Japan and they needed this breakthrough to compete with US companies. This breakthrough was foundational in reducing costs to the point that Japanese companies "stole" US markets for VCRs, TVs, radios and other electronics. Consider the level of courage to go against engrained beliefs and persistence this change required.

Developing this courage to believe a great solution is achievable is one of the great disciplines that innovator's possess. When obstacles appear along the way, your persistence will keep you head and shoulders above the rest.

> *One of the greatest discoveries a man makes, one of his great surprises, is to find he can do what he was afraid he couldn't do. Henry Ford*

<u>Summary: Ideality versus trade-offs, Inventive Responsibility, Courage, Persistence</u>
Knowing specifically which characteristics to develop provides a solid basis for measuring the impact of training and development programs and to assess their influence (ROI) on delivering positive results.

Innovators think differently. First the inventor examines psychological inertia and even though it seems impossible, expects a solution is possible without needing trade-offs. The most basic assumption an innovator makes it that there is indeed an 'ideal' solution (Ideality). This is the first and most profound difference between traditional problem-solving and innovation.

Innovators put credence in ideality and set the ideality standard as high as possible (as much as the culture or individual can personally and effectively handle) because innovators can envision that ideal, resource-efficient, non-incremental, non-obvious breakthroughs are achievable. Innovators are confident they can navigate the uncertainties and deliver results. They have conviction that they will succeed. Or, at least they act as if they will succeed - they begin 'as if' and they persist. Resolve is another great asset of the innovator.

If you want it to be different from the status quo (create inventive-level solutions), you must set the standard high. Others will be busy re-hashing old ideas again and again.

> *Thinking is the hardest work there is, which is probably the reason why so few engage in it. Henry Ford*

There will be a lot of uncertainty in the innovation process, but that is exactly where opportunity is. Just like Columbus at the edge of the world understood - just like the pioneers of the old west and immigrants that grace America today understand great possibility lays hidden within the unknown. Facing an unknown may deliver an extraordinary future. Just so, the innovator knows that going into uncharted territory is difficult, 'dangerous' work but it is rife with possibility. When there is no map, no mentor, no understanding of how to proceed, it takes courage and determined commitment to enter into chaotic possibilities and pitfalls. In this place, nothing has been filtered or tamed or organized. The rules do not yet exist and the choices have not yet been made, thus limitations are few.

Pioneers and innovators proceed, placing their trust in their tools and in their own skills. Until innovation-muscles are fully developed, it may be scary to begin. But just like any discipline, the more you proceed and succeed, the more you trust yourself and the easier it is to begin the next time.

What's right about America is that although we have a mess of problems, we have great capacity - intellect and resources - to do some thing about them. Henry Ford

Structured Innovation is the toolset for facing unknown problems and Ideality is the required mindset for using those tools. With courage and persistence innovators are armed to deal with the unknown and create breakthroughs.

Change & Secondary Problems

Organizations, societies, cultures, and groups-of-any-kind are designed for stability. They are evolved to deal with a particular *as-is* condition. But since technology is developing faster than ever before, and with multi-disciplinary knowledge converging, and with the current aggressively competitive environment, organizations must be ready to change continuously, change intelligently, and they must increase their "surface area" to the outside world (influences).

Successful leaders over the short *and* long term must doggedly address change. Great leaders do not get mired in the romance of their own history, traditions, and past successes (psychological inertia). Great leaders constantly adjust to meet changing conditions because cutting-edge technology dulls over time.

Successful business may fold under competitive pressures. Advantageous situations degrade, despite best efforts. Change is relentless. Change erodes solid foundations, good ideas, and well-knit teams. Change chips away at our education, our skills, and our position. Competitiveness (pursuing ideality) means adapting well to change. One must be bold and gutsy enough to pursue ideality, and also build stability for their group, and must simultaneously face the “facts” within the constantly adjusting situation.[50] It takes humility to realize even great solutions may fail or may create consequential issues. And those issues may look trivial at first but have deep ramifications later.[51]

This is so important and is so often misunderstood or overlooked, the authors are going to step through this slowly from an innovator’s thinking process, which is (as usual) different than most people’s thought process. Let’s start with the basics. Change is a fact of life, but it is not all bad. In fact, change is a goal of any solution. When we have a problem (inertia), we need a change to make it better. Therefore:

[50] Jim Collins (2001), *“Level 5 Leadership: The Triumph of Humility and Fierce Resolve”;* Harvard Business Publishing

[51] Example: (A) Motion JPEG (MJPEG) video was predicted by the science press to be the future winning format for streaming video because of its excellent resolution, easy edit-ability and simple streaming concept. MPEG-x as a format had many problems including the inability to edit the format. However, MPEG-x won as a preferred web format due to its excellent compressibility, low bandwidth requirements for streaming and ultimately resolving the ability to edit. MJPEG never re-addressed the primary evolving market issue of reducing bandwidth requirements once the solution was in place since it held a superior position. They did not act on how changes the competitor could make (change) would affect them. As the situation changed MPEG-x slowly eroded MJPEG’s position. (B) Microsoft over a ten year period eroded Apple’s Graphical User Interface with their windows product. Apple did nothing to continue their differentiation through innovation and nearly went out of business losing both market share and relevance.

(Problems requiring solutions) + any solution = change.
Therefore, problems require change.

One of the main reasons engineers are valued is because engineers are fundamentally change-makers. When they dependably produce positive change they are held in high esteem. Engineers constantly try to discover and eliminate the main causes of specific types of problems and they are continuously improving the *as-is* condition and developing new *to-be* processes that are better, faster, and/or cheaper. Therefore,

Improvement as a subset of any solution = change

Engineers develop methodologies and systems and use tools with the sincere desire to evoke positive change: Continuous Process Improvement (CPI), Lean, Six Sigma, Voice-of-the-Customer, Business Process Re-Engineering (BPR), EPR tools, Decision Analysis, Genetic Algorithms, Finite Element Analysis (FEA), Structured Innovation, Supply Chain Management, etc. Engineers like to believe that every effort we make towards positive change is effective and will produce great results. However, anyone who has spent time in the business world knows that does not directly correlate:

Great effort + sincerity ≠ consistent successful outcomes

If in doubt about this, ask any hands-on employee about the outcomes produced by the "latest fad" initiated throughout the company. Even when the best people are assigned to solve a problem, even when teamwork is solid, even when excellent education and robust experience are applied to a solution, and even when the most cutting-edge tools are properly used to resolve an issue, sometimes solutions work well and sometimes they fail. To date, there has never been a tool or a talent identified that unfailingly delivers beneficial-change every time. In fact, most often:

The same goal + same methodology + same experience + same company = uneven results

Why this is so is a mystery to most leaders. However, innovators know what lies at the heart of this conundrum:

Change of any kind introduces issues

Savvy engineers will not be surprised by this. But, it may be difficult to articulate. Structured Innovation has reduced the idea to its essential nature:

Change creates problems   *or*   *Change = problems*

Bad change = problems; good change introduces different problems. Fast change = problems; gradual change = problems. Change = Problems; especially when anyone reaches the edge of what is known. If you solve a problem, you will introduce new problems into the system. This is one of the reasons humans instinctively resist change. People would rather deal with the problems they are familiar with than face the possibility that the newly introduced problems will be more than they are capable of handling.

In the heart of every human, we know change equals problems; and yet we would rather not face it directly - we would rather ignore change (psychological inertia). In the heart of every good leader and great engineer is the hope that a tool (or methodology or system) can be developed without introducing problems - that hope drives our efforts. Successful innovators and inventors are different. Innovators do not resist the idea that Change = Problems.

Structured Innovation has named this phenomenon, *Secondary Problems*[52], because new issues are always introduced as a secondary result of solving the original problem. If the problem definition is ideal enough, the secondary problems may be anticipated. There are structured innovation tools to anticipate secondary problems, failures, and unintended consequences, and thus facilitates an organization's ability to problem-solve and change.

So, robust engineering and business tools such as CPI, Six Sigma, BPR, VOC, EPR, etc. will solve problems and change the situation. Most leaders and engineers stop thinking at that point. They hope this new tool will create positive change. Period. That is where the wall goes up. Innovators, however, know that there is more to the logic string. Not only will great business tools solve problems and therefore, create changes within the situation; it is also true (guaranteed, even) that those changes will create new issues because problems are a fact of life around change.

Let's pause for a second. Previously in this paper the authors' said, "In a nutshell, Structured Innovation is a scientific approach to problem-solving." Since the discipline of Structured Innovation fixes problems (thus introduces change, which introduces secondary problems), how is it different than any other tool engineers are comfortable with?

Structured Innovation *systematically* addresses secondary problems (e.g., by pursuing Maximum Tolerable Ideality without trade-offs) throughout the processes - that is a main difference and an advantage. It seems such a small paradigm shift, but this subtlety is another shift towards responsibility and away from reactivity.

In a nutshell, Structured Innovation is different than Continuous Process Improvement, Lean, Six Sigma, IDEF, DFMA-DFSS, BPR, Voice-of-the-Customer, EPR, Decision Analytics, Branding, Channel Management or any current issue-resolving initiative because all of these tools *create change and change causes new problems, and what is really needed is a core competency in solving problems - all problems - as they arise (and preferably before they happen), quickly and effectively, on-demand, and for good so they stick*. To do that, the problem-solver must address change throughout the process. This preventative mindset is to be applied as a part of every problem-solving effort and every inventive effort.

So, now it makes sense to say the foundational skill an engineer or leader must have is the ability to solve problems - the correct problems at the right time with the correct mindset. It does not

[52] 'Secondary Problems' is a TRIZ technical term defined by Genrich Altshuller.

matter whether a company or individual is intrapreneurial[53], entrepreneurial or traditional, right-brained-thinker or left-brained, creative, process-oriented, risk-averse, quality-focused, customer-driven, or marketing-competent. Problem-solving fits all cultures.

Problem-solving resolves constraints in process, cost, reliability, quality, test, compliance and regulatory issues or other events while improving performance (and without the necessity of trade-offs). Structured Innovation, by its very nature, resolves problems - and secondary problems. The 'harder' the problem is, the more helpful it is to use Structured Innovation to solve it.

One of the most tenacious secondary problems is resistance from the environment (psychological inertia). This predictable aspect of change requires courage and persistence to help overcome and counteract the prevailing habits and observable behaviors within the system. And people within the system do not generally like their prevailing habits and observable behaviors "messed with". Why does resistance exist around change?

> *Resistance is a crisis of mindset. Dayna Hubenthal*

Initially, people do not want to change. It is more comfortable to continue as they have been, to draw on their vast store of experience, to perform their tasks in the way they are skilled at and recognized for. Change may expose them as less knowledgeable than they are currently viewed. Change will dislodge some people's power structure and support system. Instead of habits and the comfortable observable behaviors of the community around them, people may be forced to enter uncharted territory, and they cannot plan for it because they do not yet know what it will be like. Any or all of this may intentionally or inadvertently cause progress to be stopped.

Mindset comes from habits and constant observable behaviors within the community. Continuity and common experience build momentum. There are power and money structures dependent on the current inertia. So, when initiating change, the change-agent must realize that an equal and opposite force is needed to counteract resistance. To ask a culture to change is asking a lot; the innovator must plan for this.

If handled incorrectly, the change-maker will be attacked and reviled. Even when handled correctly this reaction may occur anyway. It is responsible and wise to address resistance early in the process and throughout the process.

> *We are all faced with a series of great opportunities brilliantly disguised as impossible situations. Charles R. Swindoll*

Finding that correct 'opposite force' is part of the innovation process. It takes effort. And that is an effort most up-and-coming leaders find uncomfortable. In the old paradigm, leaders imposed dictates from the hierarchical "above" position. It was easy to impose sanctions or replace populations who resisted. For example, during revolt, we drive out the people who 'endanger us'

[53] Gifford Pinchot (1985), *Intrapreneuring: Why You Don't Have to Leave the Corporation to Become an Entrepreneur*; Harper-Collins. Also, http://www.intrapreneur.com/MainPages/History.html Last accessed on January 8, 2010.

and replace them with new people (or ideologies, systems, and organizations). This produces two typical results:

- The new people may be skilled and educated in the same manner as the ousted ones. They may be connected to the system in the same old ways so they have corresponding psychological inertia. This means they will likely re-create the same types of problems as the old guard. That is not really a solution.
- Or the new population may be completely different and therefore not meld with the old system, traditions, beliefs, and support, causing chaos and disenfranchisement. They may lack the necessary skills to interact with the community.

Therefore, in an old-paradigm situation, what we really have is a trade-off choice. We choose to replace the problems in order to achieve something different than what existed before (this is what we want) at the cost of relationships, experience and skills that may be valuable in the future (what we do not want). Trade-offs are the typical by-product of unexamined solutions and lack of ideality. And in most cases, the best concoction of a trade-off will be an incremental, next-step solution.

Summary

A new understanding about innovation has been pioneered. Approximately sixty years ago, Genrich Altshuller overturned the established innovation paradigm in a revisionary revolution. This rival paradigm acknowledges that innovation sometimes occurs like a lightning-strike of brilliance, but humans are not limited to that scenario. We can now take direct control of the creative process. No longer is the process of innovation inscrutable. Just like calculus and other useful disciplines, innovation has been scrutinized, understood, organized, tested, and the resultant theories have been rigorously applied to various scenarios. Today, that new paradigm is diffusing throughout the relevant scientific and social communities. Inventive-level problem-solving is developed to the point that it can be reliably performed and is in the beta-tester/early-adopter phase.

- This paper has introduced research about innovation, which is today's stated differentiator.
- It has hopefully dispelled myths that have limited even Silicon Valley's innovative greatness.
- It has also explained that invention can be a structured process, which is evolving into an applied science.

Since innovation is Silicon Valley's brand, it makes sense for Silicon Valley engineers and up-and-coming captains of business to utilize these concepts early on: to test for new constraints; apply the theories, make note of, explore, and talk about the new paradigm - in other words, to lead and to work through the misunderstandings, advocate the concepts, expand the science, correct when misapplied, stretch the known limits and succeed in ways people-of-the-old-paradigm can no longer ignore. This is the responsibility of innovative individuals, companies, and even governmental entities.

For clarity's sake, here is another way of putting this. Here is the high-level company (or governmental, industry-level, or individual) take away: if you want to be an innovation leader, jump in and get involved now. Act like an early-adopter. Find the rest of the early-adopter community and connect with it. And then do the work.

Right now the world is watching. For those blind to this innovation paradigm shift, the Silicon Valley environment is all they can see. Because innovation occurs largely inside the mind and therefore leaves few visible clues, the environment surrounding repeatable innovation is the most obvious vestigial marker. Those clues observable in the environment are merely shadows of a direct process that effectively creates “a controllable fire of knowledge”[54].

It is important to note, however, that not everyone is watching Silicon Valley. There are pioneers all over the world and they are not waiting for anyone to show them the way. They possess the requisite drive, courage, and motivation to find this information and to head into uncharted territory. Structured Innovation tools and language support the trip into uncharted territory.

Part of that language is the concept of *Psychological Inertia*. Psychological inertia becomes problematic when an individual (team, company) cannot produce the results that must be delivered. At this point, the first most important skill an individual (team, company) has is the ability to constantly examine the prevailing mindsets within the system/situation. Mindsets, ‘facts’, inertia are based on a reference frame. Just because something has always been true, does not mean it always will be truth.

Mindset management is useful when an individual (team, company) is stuck and it is also imperative when an individual (team, company) feels constrained by a situation. Innovators realize they are affected by external impingements only because the situation-they-nurtured has made them vulnerable to those constraints. External constraints ≠ automatic impingement; there are too many anomalies and contrary examples contained within that correlation for it to be ‘true’.

Innovators realize the value of keeping ‘identity’ separate from ‘beliefs’ - keeping thoughts pliable. And innovators also are skilled at holding two apparently contradictory beliefs in their awareness simultaneously:

- Belief one - It is absolutely possible to achieve our desired outcome (ideality); we can make it occur (fierce resolve); and
- Belief two - The brutal facts are: the current reality is deemed true and there is no known or acceptable[55] path to a solution that currently exists (humility, courage, flexibility).

Pioneers and inventors must exercise the muscles of courage and persistence. Courage to face chaos takes practice. Developing the will to start out when others insist it is impossible requires practice. Tolerating (pursuing) more and more ideal solutions by actively managing Ideality’s Essential Tension requires constant rehearsal. Doggedly persisting when secondary problems crop up or obstacles loom - this takes training. One must fit into the culture (psychological inertia) of their company, but not be of it, in order to be an effective innovator.

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[54] G.S. Altshuller (1984), *Creativity as an Exact Science*: *The Theory of the Solution of Inventive Problems*. Gordon and Breach Science Publishers Inc. (Fourth Printing 1998)

[55] Dana W. Clarke Sr. (1994), *TRIZ: Through the Eyes of an American TRIZ Specialist*; Published by Applied Innovation Alliance. “No known or acceptable path to a solution” – the rationale is that a known solution may exist but it cannot be used for a reason.

- Competitiveness means adapting well to change. Any change equals new problems, so the relevant engineer and/or leader must be equipped to solve problems.
    - Change causes secondary problems and what is really needed is a core competency in solving problems - all problems, as they arise (or before they happen), quickly and effectively, on-demand, and for good so they stick.

Structured Innovation is an emerging science with a comprehensive set of tools for going into wilderness of creating breakthrough solutions. Ideality is the mindset that creates the impetus and courage to forge ahead. Then with fierce resolve and humility one is ready to face the unknown.

> *"Innovation has nothing to do with how many R&D dollars you have. When Apple came up with the Mac, IBM was spending at least 100 times more on R&D. It's not about money. It's about the people you have, how you're led, and how much you get it." Steve Jobs, Fortune, Nov. 9, 1998*

> *"The cure for Apple is not cost-cutting. The cure for Apple is to innovate its way out of its current predicament." Steve Jobs, Apple Confidential 2.0: The Definitive History of the World's Most Colorful Company, by Owen W. Linzmayer*

> *"I didn't see it then, but it turned out that getting fired from Apple was the best thing that could have ever happened to me. The heaviness of being successful was replaced by the lightness of being a beginner again, less sure about everything. It freed me to enter one of the most creative periods of my life." Steve Jobs, Stanford University commencement address, 2005*