A Study of the Necessary and Optimal Conditions for Success in the Most Challenging Human Endeavors:

Modern Day Manhattan Projects are Needed for Overcoming Contemporary Global Challenges

by

Anando A. Chowdhury

B.S. Chemical Engineering/Biomedical Engineering, University of Rochester
M.S. Chemical Engineering, University of Rochester/Los Alamos National Laboratory

Submitted to the System Design and Management Program of the
MIT School of Engineering and MIT Sloan School of Management in
Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering and Management

at the

Massachusetts Institute of Technology
May 2012
[June 2012]

Signature of Author:__________________________________
Anando A. Chowdhury, Fellow
MIT System Design & Management Program

Certified by:__________________________________
Patrick Hale, Thesis Supervisor/Advisor
MIT System Design & Management Program

Accepted by:__________________________________
Patrick Hale, Director
MIT System Design & Management Program

A Study of the Necessary and Optimal Conditions for Success in the Most Challenging Human Endeavors:

Modern Day Manhattan Projects are Needed for Overcoming Contemporary Global Challenges

by

Anando A. Chowdhury

Submitted to the System Design and Management Program in Partial Fulfillment of the Requirements for the Degree of Master of Science in Engineering and Management

ABSTRACT

It is possible to categorize four contemporary challenges as the greatest threats to global well-being and the persistence of humankind. These challenges are global climate and ecological change, poor human health management, violence (or the absence of peace), and poverty and hunger. If our children, grandchildren and great-grandchildren are to survive in a peaceful world where fruitful progress can occur, these contemporary global challenges must be addressed thoughtfully and collectively as a human species.

It is the contention of this paper that there exists an optimal and necessary set of requirements and conditions (at a global and organizational level) that give us the greatest probability of success in tackling these most urgent human challenges.

The goal of this thesis is to prove this hypothesis and that these conditions can be explained by causal models as well as empirically tested through historical application and validation and direct application on a real world situation. A simple model for assessment of potential success for addressing the most challenging human endeavors is delivered. Sub-goals include presenting an analysis of the current global approaches to solving the major human challenges and how they can be improved.

Thesis Supervisor: Patrick Hale
Title: Director, MIT System Design & Management Program

This page is left intentionally blank.

ACKNOWLEDGEMENTS

Any difficult and rewarding thing can ever be accomplished by one individual alone. I wish to acknowledge below the various actors that have made the initiation and near completion of my entire program of study at MIT. I do so with fear that my meager words can never adequately represent the full gratitude I feel deep in my heart.

To my wife Natalia Chowdhury: You made it possible. Through the endless, brain-numbing assignments, the trips to Cambridge, late night and early morning conference calls and meetings, stressful and happy periods, the constant juggling of family and work commitments and travel… you never once complained that I was doing this. Rather, by being supportive through this lengthy process and being encouraging when I needed it (and I needed it often!), you made it possible. You did this all while excelling at your own work as a physician and being a great mother to our two babies, so they never felt my absense. You helped me accomplish a dream that I had for myself and for our family. Thank you.

To my sponsor Michael P. Thien: You made it all possible. Thank you for your support and belief in me in all that I do. You have plunged me into so many meaningful endeavors at work and the richness of each experience and each challenge has built the mental sinew that not only made this study possible but also honed the various other skills I attained at MIT through continuous practice in real life situations. You made be think at every moment that this is something I can do and something I should do. You knew it would benefit the company, our organization and me. You have been a great role model and a physical embodiment of how personal character, strength of leadership, inventiveness and innovativeness (backed by a history with MIT) can deliver true global impact and inspire thousands in an organization to do the best they can each and every day.

To my advisor Patrick Hale: You made it possible. Thank you for your guidance. Your steady hand in leading this remarkable program has taught me so much about what it means to be a true leader. Your guidance is always so rich with practicality while carrying behind it the weight of so much experience and forethought. As an advisor you did not discourage the breadth of the topic I chose to study in this thesis, yet had salient and valuable advice on how to make it possible and achievable while still living up to my true grand intent. As always, you were encouraging in the most helpful ways, with bona fide and tangible recommendations at every step and yet gave me the space that was needed to see through the vision.

To my parents Anwarul Karim and Mariam Chowdhury: You made it possible. Thank you for giving me my values, teaching me compassion, teaching me tolerance for all humanity, and making me believe at all times that I could do anything I set my mind to. You allowed me to explore my interests and my passion for science at a young age. Thank you for raising me to be at once secular in my actions and assessments but deeply spiritual in my emotions and empathy. You taught me to be kind and respectful and to

feel a sense of something in the world. Ma, you would make me sit and focus on my work (as you knew I would always fidget). Who knows where I would be if you had not made me sit next to you every night and study. And you made sure that I had the right tutors who taught me science and math and writing and made sure they stayed away from evangelizing about faith (a real problem at times!). Your tender wish that I live up to my full potential is and always will be a great inspiration for me. Abbu, thank you for giving me a rich, diverse and global life and making me a global citizen. Because of you I have had life experiences that very few people have. I understood from a very young age that what set you apart was the substance and fact-based scientific understanding that you put behind the noble aspirations you have for building a culture of peace, sustainable development and the improving the plight of women and children. I have learned from watching you in global affairs that the bias for informed action while building alignment is the only way of making meaningful substantive change. And you have taught me through example the importance of parting abruptly from empty rhetoric. It is through watching you lead and shape diverse organizations and mobilizing them and then your emphasis on demanding the best out of people that has provided a blueprint for how I intrinsically lead and what I expect from others. You showed me how to blend pragmaticism with an unwavering commitment to the larger purpose. You have also have shown me how unabashedly caring and devoting oneself to work for a greater global good is what we should expect of all humanity.

To my siblings: You made it possible. By always being there for me and believing that your little brother could do anything. Even when I didn't feel that special, you guys made me feel special (sometimes superhuman) To my sister Sudeshna, you made it possible. Thank you for raising me in the most loving way a person can and for being responsible for any good that I have ever done or accomplished. For always believing in your brother and for always being proud of what I have done. I can remember the happiest moments growing up was when you would look at something I drew or wrote for school and then say "That's my brother!". And you followed that with why you thought it was good, whether it was because I described something well in prose or it was the color combinations I used. And you were such a caring supporter of anything I did and loved me unconditionally. All my quirks were lovable to you. I could tell you everything and you built up my character from a very young age. To my brother Shantonu, thank you for always supporting me and my ambitions and always giving pertinent advice on life and how to proceed. From you I learn how to create an environment for my family that is caring, nurturing but also solid with practical security. You taught me how to put the meat behind the ambitions and how important it is that one should balance the commtiments they have to heir family and the commitments they have to themselves and their career. At every important juncture in my life, be it my first car, or my move to college, you have always been there in real ways to help and enable major inflection points in my path to maturity. And through out this whole process, whenever I spoke to you about the trials and tribulations of balance or family issues, I felt that we had a common understanding and it helped me get through. To my brother-in-law Shahid, you have been helpful and so caring towards me all the time I have known you. I still feel that in many ways, even though I have matured in years, you still hold the same affection for the little boy you met so many years ago! It is very sweet and gives me a license to still be vulnerable. To my sister-in-law, Margaret, thank you for your loving care and encouragement any time I am around you. You always have such amazing advice and your outlook on the world is one filled with love and putting what is important first. You have a way of understanding worry in someone, and it is always a pleasure to talk through things with you. You have an amazing spirit and always inject energy into life while making things easier for everyone like a big weight taken off one's shoulders.

To my growing family: You made it possible. Nabil and Rebecca Raoof. I could not ask for better father-in-law and mother-in-law. You have supported us in so many ways, from advice through helping with our kids, our house and home, and our every day lives. Without you, completing this program would be impossible. Thank you for your moral and physical assistance through all of this. Your hard work and true love and dedication you have towards the family is so inspiring and has inspired me to drive to achieve more. Nina, thanks for giving me the best wishes and love through the process, all of which was physically embodied in my lucky bamboo plant! Since the GMATs to the thesis, that plant has provided great fortune in traversing through the tough times and I believe it is because it was awash with your good wishes. Nazar and Tejal, thanks for keeping up and always being curious about my progress at MIT even with the monumental changes in your own lives! It was always great to know that you had our backs when I was not there for work or school.

To my friends: You made it possible. I know that no matter what happens, that you have my back and I have yours. This is a blessing that very few have in friends. You are a group of friends that are also my family and this program could not have been done without you. To my friend Zhi M. Liao for being as much a big brother to me as a friend. I owe a lot of the man I am through your example and couldn't have finished this without being the man you helped me become. Thank you for always being there for me and my family and for taking me in in the very beginning! To Stephanie C. Weiss for being a confidant and best friend. I could not ask for someone more special than you to encourage and support and always be there in every possible way through this whole effort. To Irene Lachance and Steve Lachance for being my family here in New England, I felt stronger in knowing that I had you as family close by, thank you for the emotional support. Kenyon Binns, Pete Chalif and Naji Anaizi, I don't think I could have survived without the wonderful man weekends together to blow off steam and power up. Pete, Gale Segarra-Roberts, Gregg Roberts, Jen Tang, Bhanu Dhungana, Harpreet Nijher and David Maine, thank you so much for your emotional support, advice and tangible help and real connections as my family was going through some really hard health issues right in the middle of my program. You helped me help my family through it big time.

To my teachers: You made it possible. The love you gave me for learning has no price. I only hope that through my deeds I can pay you back in some small measure. Craig Olstad (ASIJ), Don Chambers (ASIJ), Eldred Chimowitz (UR), E Zuk (PS 158), Giles Cokelet (UR), John Ferron (UR), John Friedly (UR), Marcia Soberman (PS 158), Peter Kennedy (ASIJ), Samarendra Karmakar (SFXGH), Steven Buelow (LANL), Sylvia Berg (PS 158) – to every single person in the MIT faculty who I have studied under – you are an inspiration.

To my mentors at work: You made it possible. I carry many of the lessons you have taught me either directly or through your example. Many of the principles I have formulated come from you. Thank you for your inspiration, direction, ideas and belief in me. Thank you most of all for taking the time to contribute unselfishly to my development and progress. Alex Hasson (Merck), Allan Schwartz (UHS), Amnat Choepatkul (UNICEF), Chris Howell (EKC), Craig Hollenbeck (EKC), Gary Hoffman (Merck), Glen Pearson (EKC), Ivan Donahey (EKC), Jim Robinson (EKC), Jon Wilder (MDT), Karen Gleasman (EKC), Kathy Sweetland (UHS), Mark Haboian (EKC), Neil Farukhi (EKC), Pedro Jimenez (EKC), PK Yegneswaran (Merck), Robert Cournoyer (EKC), Tom Bucuk (Merck)

To my work colleagues: You made it possible. I have had the honor of working with each of you. Being around you has always given me strength and resolve and a feeling that together we could accomplish really hard and important things. It is through you I have learned the mean of the words "teammate" and "colleague". Thank you for inspiring me with your passion and talent in what you do. Alan Didas, Ben Unger, Bo Lee Cook, Brian Aylward, Carl Testa, Chris Palte, Craig Hollenbeck, Dan Doyle, Dan Hoey, David Bendert, David Wride, David Vossen, Elizabeth Dykes, Frank Sorg, Geoff Nagel, Jamie Hyde, Jeff Blinn, Jim Linz, Jim Zega, Jim Thornburg, Karen DelGaudio, Lew Smith, Liam Dunne, Mark Eder, Mark Fornalik, Mark VanWuyckhuyse, Melanie Marshall, Michelle Marshall, Mike Hobbs, Mike Sanchez, Nancy Geisler, Poppy Kroese, Scott Osher, Sesh Jagannathan, Sridhar Sadisavan, Suresh Sunderajjan, Terry Brethen, Terry Clas, Tom O'Brien, Viviane Massonneau

To MIT Fellows and new friends: You made it possible. You all made the experience fun. I have learned from all of you and it has been an honor to work side by side with each of you on projects, teams, assignments, discussion groups, reports and initiatives as we climbed each rung of the MIT journey together. Thanks also for the millions of times you all covered my back through the myriad challenges and competing priorities in my life! Amith Pervaje, Azamat Abdimomunov, Cindi Hernandez, David Morgan, Doug Schofield, Eduardo Cavalari d'Oro, Gaurav Agarwal, James Paul Perunvakul, Jeffrey Davis, Jess Posey, Jose Fuentes, Kris Cowart, Leigh Gautreau, Leyla Abdimomunova, Mario Montoya, Mark Moran, Mona Masghati, Palani Perumal, RJ Lehman, Rukthai Ace Prupark, Sahar Hashmi, Taroon Aggarwal

Special thanks: Glen Pearson, who inspired me and advised me to do MIT-SDM. And to Chanland Roonprapunt, MD and Susan Boolbol, MD for being not only exemplery physicians, but exemplery human beings. You helped my family through some of the most difficult moments during my time in this program. You made miracles happen with your expertise, judgment and genuine care for the best outcomes.

And to Isaac Asimov, who translated the wonder of science to a young boy and through the power of the pen had a profound influence on my life.

This page is left intentionally blank.

This page is left intentionally blank.

Dedicated to my children:
Xavier and Olivia

And their cousins:
Pryanca, Gabriela and Zander

May we leave to you a better world and may you do a better job than we have in keeping it well.

This page is left intentionally blank.

TABLE OF CONTENTS

SECTION 6: ACTIVE CASE STUDY AND DIRECT APPLICATION OF THE NECESSARY CONDITIONS MODEL 89

CHARTS & FIGURES & TABLES

This page is left intentionally blank.

ACRONYMS

AIDS:	Auto-immune Deficiency Sysndrome
ARPA:	Advanced Research Projects Agency
COUHES:	Committee On the Use of Humans as Experimental Subjects
DSM:	Dependency Structure Matrices
FDR:	Franklin Delano Roosevelt
FMRI:	Functional Magnetic Resonance Imaging
JFK:	John Fitzgerald Kennedy
IAC:	InterAcademy Council
IBM:	International Business Machines
KPI:	Key Performance Indicators
LANL:	Los Alamos National Laboratory
MAD:	Mutually Assured Destruction
MDM:	Multi-Domain Matrices
MIT:	Massachusetts Institute of Technology
NACA:	National Advisory Committee for Aeronautics
NAE:	National Academy of Engineering
NAS:	National Academy of Sciences
NASA:	National Aeronautics & Space Administration
NGO:	Non-governmental Organization
NIH:	National Institutes of Health
PMTP:	Pharmaceutical Manufacturing Technology Platform
RCA:	Radio Corporation of America
SAGE:	Semi-Automatic Ground Environment
SAPARP:	System Architecture Principles Adherence Radar Plot
SEC:	Securities & Exchange Commission
SLaM:	Sterile & Large Molecules
SODS:	Solid Oral Dosage & Specialty
SOFI:	State of the Future Index
TAT-1:	Trans-Atlantic Telephone Line 1.
TB:	Tuberculosis
UN:	United Nations
UNDP:	United Nations Development Program
UNEP:	United Nations Environmental Program
Unicef:	United Nations Children's Fund
X-Mod:	Cross-Modality

This page is left intentionally blank.

SECTION 1: INTRODUCTION

The Millennium Project has established some very important goals and challenges that face humanity moving forward into the future. This ambitious project was set up by the United Nations University, the Futures Group, and the Smithsonian Institution in 2009 to layout and update progress on the 15 fundamental global challenges facing humanity. These are listed below.

Table 1.1: Millennium Project list of Global Challenges Facing Humanity (2009)

1. How can sustainable development be achieved for all while addressing global climate change?
2. How can everyone have sufficient clean water without conflict?
3. How can population growth and resources be brought into balance?
4. How can genuine democracy emerge from authoritarian regimes?
5. How can policymaking be made more sensitive to global long-term perspectives?
6. How can the global convergence of information and communications technologies work for everyone?
7. How can ethical market economies be encouraged to help reduce the gap between rich and poor?
8. How can the threat of new and reemerging diseases and immune micro-organisms be reduced?
9. How can the capacity to decide be improved as the nature of work and institutions change?
10. How can shared values and new security strategies reduce ethnic conflicts, terrorism, and the use of weapons of mass destruction?
11. How can the changing status of women help improve the human condition?
12. How can transnational organized crime networks be stopped from becoming more powerful and sophisticated global enterprises?
13. How can growing energy demands be met safely and efficiently?
14. How can scientific and technological breakthroughs be accelerated to improve the human condition?.
15. How can ethical considerations become more routinely incorporated into global decisions?

As we contemplate this list it is clear that parts of the list are actual outcomes that we are wishing to achieve and some of them are enablers that are based on principles that we have agreed to as important for humanity. In the context of a complex engineering system, we would consider the outcomes as the intended big Y variables and the enablers as our little X variables in an equation formulation $Y = f(X)$. For instance, if we look at question number #5 in the above list, which talks about the need for policymakers to develop a sensitivity around global long-term perspectives, we can argue that this is a prerequisite (X's) to be able to solve some of the lagging problems (Y's) around sustainable development, availability of clean water and addressing global climate change, which are the topics of some of the other questions in the 15 millennium challenges. It is thus important to differentiate outcomes that we are trying to achieve as humanity and the pathways to reach those outcomes. This will develop some level of crispness and test some of the fundamental assumptions that are embedded within the 15 millennium goals.

In parsing the outcomes from the broader list of 15 it is possible to categorize four contemporary challenges as the greatest threats to global well being and the persistence of humankind. These are global climate and ecological change, poor human health management, violence (or absence of peace), and poverty and hunger. If our children, grandchildren and great grandchildren are to survive in a peaceful world where fruitful progress can occur, these contemporary global challenges must be addressed thoughtfully and collectively as a human species.

The Millennium Project has identified a number of measures and indicators in a broader assessment, known as the state of the future index or SOFI. The state of the future index consists of a variety of leading and lagging indicators that can be directly measured globally and can be a marker for progress on change initiatives that are meant to better the world. Positive progress on these measures indicates a better state, while degradation in these measures would indicate a future of impending turmoil. If we examine the myriad measures in the state of the future index, we find that some are truly lagging indicators, in other words, those that cannot be directly influenced by our actions, as opposed to those that are leading indicators or those that can be influenced by individual or collective global action. Figure 1.1 attempts to segregate these measures into the leading and lagging categories. The leading indicators are entitled enablers and the lagging indicators are parsed by the big four challenge categories that we have identified. For the sake of simple and efficient representation, the big four challenges have been named health, poverty, peace and sustainability.

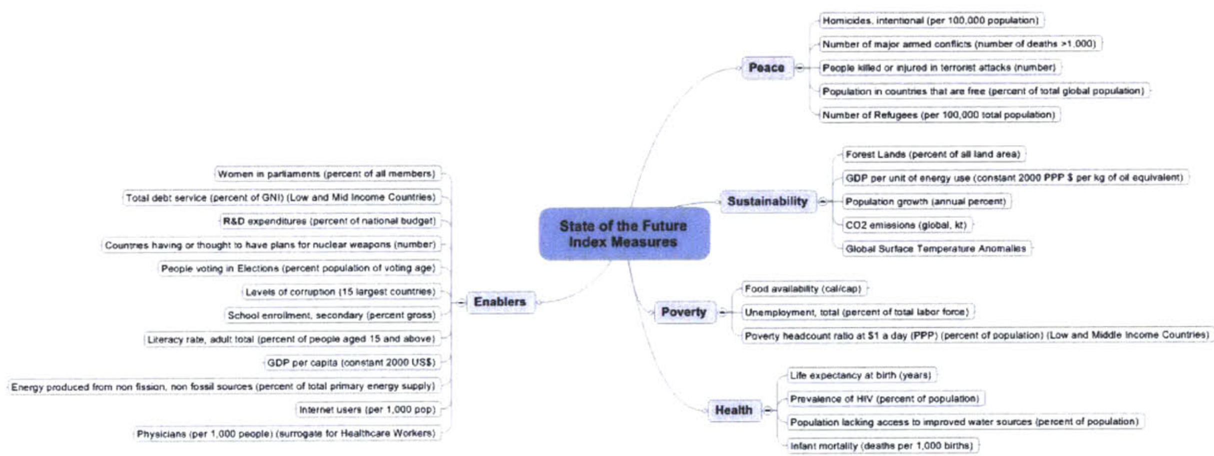


Figure 1.1: The Millennium Project – SOFI parsed by leading and lagging indicators

For example, the leading indicator of research and development expenditures as a percent of national budgets is something that collective private and government action can directly influence. While this may be difficult to do, it is well within our control to be able to manage and change this measure directly. However, if we look at one of the lagging indicators in the health category such as life expectancy at birth in years, this measure can only be indirectly influenced through several enabling actions. The ultimate outcome cannot be directly controlled, but will serve as a definitive gauge of the success of the leading efforts.

It is the contention of this paper that there is an optimal and necessary set of requirements and conditions exist (at a global and organizational level) that give us the greatest probability of success in tackling these most urgent human challenges.

The goal is to prove the hypothesis that there is an optimal and necessary set of global and organizational conditions that are needed to solve the most complex human challenges and that these conditions can be explained by causal models. A simple model for assessment of potential success for addressing the most complex human endeavors is delivered. Sub-goals include presenting an analysis of the current global approaches to solving the major human challenges and analyzing how they can be improved. It should be noted that a fundamental axiom of this paper and analysis is that socio-technical systems are at the core of being able to solve the fundamental human challenges. Thus, most of the analysis and development of assessment tools will be from the diagnostics of previously successful and unsuccessful efforts in developing mass complex socio-technical systems and entities that have had a global impact.

The first step will be to define the attributes of what makes a human endeavor challenging and complex. A formulation of challenge level will be constructed. An inductive comparison of complex challenges vs. relatively simpler challenges will be given to highlight the effectiveness of this calculation. A study of successful human endeavors will be given that cover a wide variety of domains and situations from engineering to society. A definition of "success" will be posited with qualitative and quantitative components. This study will then do an inductive comparison of successful and unsuccessful endeavors. We will choose efforts due to the availability of rich data sets and individuals who have a living account and tacit knowledge of the underlying situations and organizational circumstances leading to success. In juxtaposition, a set of unsuccessful endeavors will also be posited and studied.

An empirical study will be done on the attributes that made the human endeavors successful. These will include the engineering, management and behavioral points of view. They will be centered on the four aspects of organizational systems, the structure, the processes, the decisions and the people and assets. Where possible, causal models will be developed that explain the reasons for success. The attributes will be unique in that they are all necessary for success. In other words, the absence of any one of the attributes will lead to a lack of success. The causal models will be built from systems approaches, and these models and attributes will then be tested against the successful and unsuccessful examples to prove by induction that they are the necessary set of conditions and attributes for succeeding in the most complex human endeavors.

With the quantitative and qualitative attributes in hand, a model for testing prospective plans will be delivered. At this point, we will examine the current state of initiatives intended to improve the conditions and/or solve the four major challenges defined, i.e. global climate and ecological change management, better human health management, establishing a culture of peace, and poverty and hunger eradication with reference to the testing model. The hypothesis is that this will yield identification of inadequacies in our current global approaches. It is also hypothesized that a subset of approaches will score fairly high on some of the parts of the model, thus indicating that hybrid approaches may be generated.

We will test the theory empirically by studying how these concepts have been applied in a local complex human change: the management of global level manufacturing technology strategy of a multinational corporation.

In this portion of the analysis we will make the claim that solving for and observing the successful implementation of change within a large global organization will help us derive certain truths and allow us to make certain value judgments on our assessment model that can be inductively translated for global institutions working on the four major challenges.

With the gaps identified, a set of proposals will be offered up using a selection of innovation methods to enhance the current conditions and approaches against the testing model attributes. Looking critically at the proposals against the causal models offered up in the prior steps will also be a part of the analysis.

Lastly, a simple physical and social technology roadmap needed for turning around our current trajectory will be presented. The probability of moving from the current state to the proposed solution space will be estimated. A qualitative discussion will be offered to examine moral, societal and scientific implications.

SECTION 2: WHAT MAKES AN ENDEAVOR CHALLENGING?

We start our journey by defining the attributes that make an endeavor truly challenging. The hypothesis here is that there is a continuum of challenge levels that can be attributed to any endeavor. This continuum starts from the extremely easy and ratchets its way all the way up to the intractable. In keeping with the original premise of studying socio-technical systems, we start by defining challenge level through an empirical study of some of the most difficult achievements of the past century.

The National Academy of Engineering (NAE) conducted a study of the last century and categorized the greatest human achievements in the last hundred years. In delving into each one of these achievements, a picture and a set of factors and attributes common to all of these achievements becomes apparent. We can categorize these achievements as representing one step shy of intractable. Thus, in studying these great socio-technical achievements, we can arrive at a semi-quantitative way of assessing complexity and challenge for these broad-based initiatives. By taking this approach and identifying the set of factors which for these achievements would be set on the high end of the spectrum between easy and intractable, we can establish the boundaries of the assessment scheme by moving quite a bit away from these case studies to establish the lower bound of the scale and just a bit higher to establish the upper bound.

The selection of these socio-technical achievements was by the NAE in collaboration with the American Association of Engineering Societies and National Engineers Week. Sixty professional engineering societies were solicited for nominations from their members for the greatest engineering achievements of the 20th century. From this initial list each participating society was then asked to contribute their top five selections to the NAE. There were a total of 105 nominations from 27 different engineering societies. In compiling the list, what was of tantamount importance was the impact that the socio-technical achievement had on the very quality and fabric of life during the last hundred years. A selection committee was formed, consisting of the leading engineers and experts from all walks of life including academic, industry, government, and a wide range of engineering and social disciplines.

Table 2.1: National Academy of Engineering List of Greatest Engineering Achievement of the 20th Century.

1. Electrification	11. Highways
2. Automobile	12. Spacecraft
3. Airplane	13. Internet
4. Water Supply and Distribution	14. Imaging
5. Electronics	15. Household Appliances
6. Radio and Television	16. Health Technologies
7. Agricultural Mechanization	17. Petroleum and Petrochemical Technologies
8. Computers	18. Laser and Fiber Optics
9. Telephone	19. Nuclear Technologies
10.Air Conditioning and Refrigeration	20. High-performance Materials

The selection process of the final set of achievements was blind, so that no member of the actual selection committee was aware of the others involved. This avoided undue influence from some of the great thought leaders participating in the selection process. The names of the committee members were not released until after the final selections were made. The original list was pruned down by that selection committee to a set of essential 48 nominations for the final whittling of the list. The 48 nominations were grouped into larger categories and affinitized in a way that made sense for representation. This form of combination reduced the list further to a set of a critical 28, and the final 20 were delivered in December 1999. Astronaut Neil Armstrong announced the final list in February of 2000. The list is shown in Table 2.1.

We will examine each one of these 20 socio-technical achievements in some detail later on after the formulation of the optimal and necessary conditions. After formulation, a means of predictive analysis on the success of these complex initiatives will be developed. But for the moment, we will summarize the outcomes of this analysis to help create a semi-quantitative way of assessing challenge level for human endeavors. Studying these 20 socio-technical achievements allows us to arrive at some common ways of describing challenge level. It is clear from this analysis that there are two primary dimensions that make human endeavors challenging.

One aspect is the difficulty level in arriving at an actual solution for a well-defined or ill-defined problem. In this several dimensions of difficulty can arise. For instance, new scientific discoveries may be required in order to solve the problem or a tremendous amount of coordination must be required from a variety of different disciplines to make the solution a reality. In addition, solution complexity can also arise from the number of subsystems that must be integrated and coordinated in order to make a holistic solution. We will describe this dimension of difficulty as "**solution or design difficulty**". The other dimension of difficulty arises from the human aspects of needing to drive change across a multitude of populations in a way that impacts the fundamental behaviors of those populations. The adoption or diffusion of new things is a well-studied phenomenon within systems study. In this space, often the population cannot conceive of the future condition that would require them to change their fundamental ways of living. In some cases, the changes would be beneficial for large populations and in other cases, there may be an uncertainty and loss factor associated with the change. We will call this dimension the "**propagation or adoption difficulty**". One can create a phase space that has the propagation difficulty in the y-axis and the solution difficulty on the x-axis. The reason for referring to this simple graphical representation as a phase space is the movement along any axis is intricately linked to movement along the other axis and thus independent movement along either axis is quite rare and often realistically impossible. This two-dimensional graph allows us to map endeavors and initiatives in a space so that the challenge level can be visualized in a succinct and efficient manner, and the endeavors that make their way to the upper right-hand corner of the chart would be the most complex, difficult and challenging, while those that fall to the lower left-hand corner would be those that would be easy, common and could rely on old and well known behaviors. Endeavors that are not so high on the y-axis would be what we would categorize as those subject to epidemic adoption. That is when the population sees the innovation with the needed change, variable to envision with great clarity the benefits derived from the change. They instantaneously adopt these changes. Where's those that traverse higher on the y-axis would be those innovations and changes subject to the dynamic of probit adoption. Often those things with even the most simple solutions can have high propagation difficulty. Figure 2.1 shows the graphical representation of this phase space.

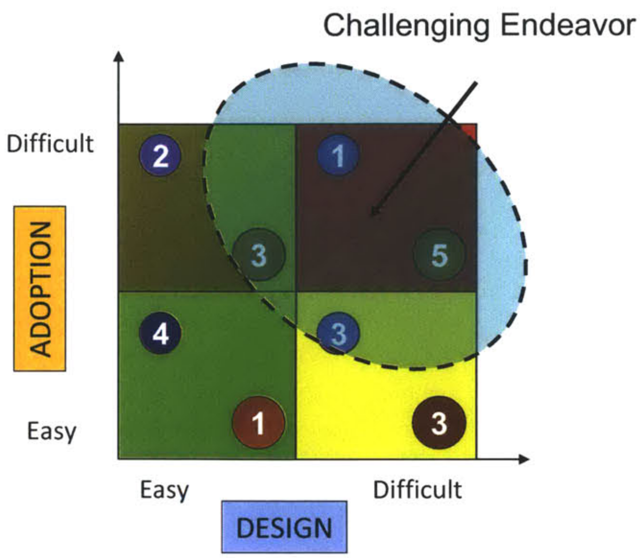


Figure 2.1: Socio-technical complexity or challenge level.

Socio-technical systems are actually combinations of physical and social technologies (Nelson, 2003). Davies (2008) presents a framework by which to assess technology in considering the technology and the system in which the technology is deployed together and in concert. Implicit in this is a recognition that the innovation in the technology is irrevocably tied to the impact that technology has on the overall system performance which, in turn, is linked to the potential applications of that system that its new or extant functionality provides. A complimentary framework is provided by Nelson (2003) in which we can consider the co-evolution of two types of technologies, physical and social. Nelson defines physical technologies as "designs and processes for transforming matter, energy, and information in ways that are useful for human goals and purposes." An example of this is turning sand into glass or into silicon chips. Social technologies are "designs, processes and rules that humans use to organize themselves," such as villages, armies, matrix organizations, rules of law, just-in-time inventory management, and paper money. A large-scale socio-technical system is thus shown from pharmaceutical manufacturing in Figure 2.2 and will be revisited later as we attempt to empirically test some of the success-predictive algorithms for complex human endeavors.

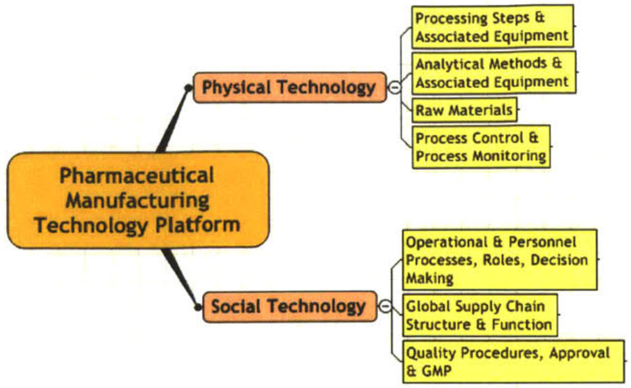


Figure 2.2: Example of a somewhat complex socio-technical system in the pharmaceutical industry (adapted from Chowdhury, 2009)

Having this definition in hand, we can address first the question of defining the x-axis of design difficulty. In the area of design difficulty we are able to access multiple methods of calculation ranging from qualitative to quantitative, from Kolomorogov complexity, to Shannon entropy, (Gell-Mann et al, 2004) to Crawley formulation from systems architecture (Crawley, 2004) or several others explored in Feldman (2004) and Crutchfield's (2004). This area is perhaps the most thoroughly studied in systems engineering and gives us the best chance to start with quantitative formulations of the x-axis. The dominant definitions are as follows:

The **entropy rate** h_μ of a symbolic sequence measures the unpredictability (in bits per symbol) of the sequence.

The **Kolomogorov-Chaitin complexity** ($K(x)$) of an object x is the length, in bits of information, of the smallest computer "program" that when run a theoretical Universal Turing Machine outputs x and then stops. This is the most fundamental version of complexity or difficulty of design from information theory.

Entropy rate and K-C complexity are approximately the same as the K-C complexity is maximum for random strings of information. Non-randomness based measures are also important as they account for structural or correlative complexity. Structural complexity can be defined by the Ulrich formulation (Makumbe, 2008). "A system is structurally complex if it has numerous components whose interactions, interconnections or interdependence are difficult to describe. Along the same lines, Maier & Rechtin (2000) define complexity as "a measure of the numbers and types of interrelationships among the system elements". We have taken a combinatorial approach that takes the information and the structural views of complexity and puts them together in this way.

$$C_D = \frac{I_T N_S N_I}{t\frac{dR}{dt}} \quad (1)$$

Here C_D represents the challenge or complexity of design, I_T is the level of technical innovation or discovery required (which gets to the information level and degree of predictability and randomness of the effort), N_S is the number of sub-systems that need to be managed, N_I is the number of interfaces (interfaces and sub-systems get at the structural complexity side of things), and R are non-temporal resources (dollars, intellect etc.) and t is time. This mathematical construct is valuable for modeling purposes, however, not practical for assessment across the complex socio-technical issues we will be exploring in the paper. Thus a simple semi-quantitative tool has been developed to assess this. This is given below in Table 2.2. In the table, the factors are represented in multinomial way using a standard quality function deployment (QFD) method of showing the factor increasing in importance through a three level series of 1, 3, and 9. There is an additional culture multiplier 1,2, 3 on how different the behavior of the design crews must change. In this multinomial way, we have chosen to represent the total design difficulty in the following way:

*Solution Difficulty = (Innovation + Structure + Resources)*Culture Shift* (2)

The sub-factors under each factor will be additive as well making the lowest possible value of design difficulty be 12 and the highest be 324. Of course the theoretical minimum is 0 and maximum is infinite in any such factor, from no change to a near intractable design challenge.

The adoption difficulty is more amenable to this multinomial approach. It is more difficult to write out the adoption or propagation difficulty as an equation that can be modeled as shown in equation 1 above for design difficulty. We have consider the factors constructed by Daryl Conner (Conner, 2006) when assessing the magnitude of a change effort. These factors have been adapted for a more global scale and are again represented in a factored way in Table 2.3. The essence of Conner's change equation can be formulated in a similar manner to the Equation 2.

*Adoption Difficulty = (Timing + Scale + Resources + Complexity)*Culture Shift* (3)

This multinomial, semi-quantitative equation has been the basis of much of the change management work that Conner has represented and does well as a summary of the efforts. The sub-factors under each factor will be additive as well, making the lowest possible value of adoption difficulty be 36 and the highest be 972. Of course the theoretical minimum is 0 and maximum is infinite in any such factor, from no change to a near intractable adoption challenge.

Table 2.2: A semi-quantitative assessment of the design or solution difficulty level.

Factor	Question	Scale		
INNOVATION		**Low = 1**	**Medium = 3**	**High = 9**
Discovery	*What level of fundamental scientific discovery will be required?*	*Prior scientific work exists making the current effort having a greater than 80% of positive outcome.*	*Some prior scientific work exists but some new hypotheses must be created on causal relationships between known entities making the current effort having a between 40-80% of positive outcome.*	*Very little prior scientific work exists or new hypotheses have to be validated in finding a previous unobserved form making the current effort having a less than a 40% chance of a positive outcome.*
Development	*What level of technical development will be required?*	*Although it may be challenging, this development has been done before at this location. There is a clear understanding of what it will take and what can be expected.*	*This development is new for those involved but it has been done before. There is access to the prior experience providing an understanding of what to expect.*	*This is a new design. Although it has or can be planned, there is limited prior experience on which to call. Therefore the understanding of what it will take and what to expect is incomplete and/or contains a high degree of uncertainty.*
STRUCTURE		**Low = 1**	**Medium = 3**	**High = 9**
Subsystems	*Number of subsystems*	*This has the average and stable number of subsystems for other socio-technical entities of its class*	*This has a large and semi-stable number of subsystems for other socio-technical entities of its class*	*This has a massive and unstable number of subsystems for other socio-technical entities of its class*
Interfaces	*How many interfaces are required to be managed*	*This has the average and stable number of interfaces for other socio-technical entities of its class*	*This has a large and semi-stable number of interfaces for other socio-technical entities of its class*	*This has a massive and unstable number of interfaces for other socio-technical entities of its class*
RESOURCES		**Low = 1**	**Medium = 3**	**High = 9**
Rate of Resource	*How fast to qualified resources flow to required activity?*	*The required resources are available at a rate faster than required*	*It requires a significant amount of time to develop and acquire the qualifed resources*	*It requires a massive amount of time to develop and acquire the qualifed resources and there is a tremendous drop off in the number of those being developed*
Time	*What is the time pressure/constraint to effect this change? How quickly will we have to finish?*	*A solution is needed in the next 4 years*	*A solution is needed in the next 2-4 years*	*A solution in less than 2 years.*
CULTURE	**MULTIPLIER**	**Low = 1**	**Medium = 2**	**High = 3**
Behaviors	*Is the way of developing solutions consistent with the existing culture? Does it require very different behaviors?*	*The activity/initiative is consistent with the existing culture. It does not require a shift in beliefs or assumptions. It does not significantly change behaviors.*	*The activity/initiative is largely consistent with the existing culture. Some change in behavior is required, but it is not radical. The activity/initiative can be accomplished with minor change in underlying beliefs and assumptions*	*The activity/initiative demands a significant shift in culture. No only are there new behaviors, but it also requires people to adopt new beliefs and assumptions.*
New ways of doing things	*How different in the daily work for those impacted?*	*For the majority of people impacted, the change is a small shift in their daily activity. They do the same job with limited changes or additions.*	*For the majority of people impacted, the change is a moderate shift in their daily activity. A significant part of what they do is different.*	*For the majority of people impacted, the change is a significant shift in their daily activity. They will see the impact every day and their roles are different.*

Table 2.3: A semi-quantitative assessment of the propagation or adoption difficulty level adapted from Conner (2006).

Factor	Question	Scale		
TIMING		**Low = 1**	**Medium = 3**	**High = 9**
Velocity	How fast is this change coming at us? How much advance warning did we have? How soon will be have to start?	There is or will be a reasonable amount of time to plan - This would typically equate to 5-8 years away.	Planning has or will be done under time pressure and with some urgency but without having to cut corners. This would typically equate to 2-5 years away.	Planning has or will require extremely high effort. There is some risk that the plan will be incomplete despite of the best efforts. This would typically equate to 1-2 years away.
Speed	What is the time pressure/constraint to effect this change? How quickly will we have to finish?	There is a reasonable time expectation to achieve minimum acceptable realizing (to show positive, sustainable benefit). This will vary with the scale of the initiative but is at least 4 years after installation.	There is a defined time in which to effect the change and a meaningful cost to the world of failing to meet this time. This will vary with the scale of the change but is at least 2 years after installation.	This activity must effect change in a very short time period and the price of failing to do so is high. It will become a high priority for all affected. This will vary with the scale of the initiative but is within 1 year installation.
Planning	Are changes planned as part of an annual planning or re-planning?	The changes are planned and are expected.	Although not planned, there was some understanding that the change might be required. Although not planned, it is not a complete surprise.	The change was not anticipated. It is a result of a change of circumstances that was largely outside the control of the local areas and impacted individuals.
Factor	**Question**	**Scale**		
SCALE		**Low = 1**	**Medium = 3**	**High = 9**
Range	How may people are significantly affected? How much of the world population does it affect?	The change impacts 20% of the global population	The change impacts 20-50% of the global population.	The change impacts more than 50% of the global population.
Connections	Is this a local change or does it require changes more globally	The change is limited to the location where it is being executed.	The change requires change beyond the location where it is being executed. The connection is in the form of linkages to the external areas.	The change requires change beyond the location where it is being executed. The external changes are significant and in effect, require coordination with meaningful change taking place there.
Impact	What is the level of impact?	The change/initiative has a meaningful but limited impact on the constituencies.	The change/initiative has a moderate impact on the constituencies.	The change/initiative has a major impact on the constituencies.

Factor	Question	Scale		
RESOURCES		**Low = 1**	**Medium = 3**	**High = 9**
Level	*What level of resource is required to execute the change?*	*The number of people needed to execute the change as change agents is small (this should be judged relative to the location) but approaches thousands of individuals.*	*The number of people needed to execute the change as change agents is moderate (this should be judged relative to the location) but approaches tens of thousands of individuals.*	*The number of people needed to execute the change as change agents is significant (this should be judged relative to the location) but approaches over hundreds of thousands of individuals.*
Effort	*What proportion of time is needed from the core resources acting as change agents? Rate the time need and not the time available.*	*The core resources acting as change agents can do so in conjunction with their regular lives. The time requirement is less than 20% on average. If there are peaks of activity where the demand is higher, it is for no more than a week.*	*The core resources acting as change agents can do so in conjunction with their regular lives but it requires significant flexibility and a challenging balance. The time requirement in less than 40% on average. If there are peaks of activity where the demand is higher, it is for no more than two weeks at separate times.*	*The core resource acting as change agents must be living and driving the change full-time for meaningful amounts of time.*
Skills	*Does the change require skills that have to be acquired?*	*The change agents have all of the skills required.*	*The change agents have most of the skills required and have access to experiences and resources where they need support.*	*The change agents have to acquire some or all of the skills needed. This includes learning or working with other skilled resources.*
Factor	**Question**	**Scale**		
COMPLEXITY		**Low = 1**	**Medium = 3**	**High = 9**
Interrelatedness	*How dependent is this change with others? Is there a high need for coordination?*	*The change is largely standalone. There are relationships to other parts of global change, but no large dependences on other ongoing projects.*	*There are limited dependencies. These must be managed but this change can achieve realization on its own.*	*There are dependencies on multiple other concurrent or changes. The dependencies are significant enough that the initiatives cannot be successful independently.*
Sophistication	*How many moving parts are there? Is it challenging to understand all of the connections? Is it hard to explain the activity/initiative to others?*	*This is a reasonably straightforward activity. It may involve a lot of work, but there are a limited number of parallel streams.*	*There are several related parallel streams. These involve different activities but they are highly related and well understood.*	*There is a wide diversity of work needed to complete this activity/initiative. Although related the breadth creates a complexity and distance between them*
Novelty	*Is this a new activity or something with which the change agents have prior experience?*	*Although it may be challenging, this change has been done before at this location. There is a clear understanding of what it will take and what can be expected.*	*This change is new at this location but it has been done before. There is access to the prior experience providing an understanding of what to expect.*	*This is a new global paradigm. Although it has or can be planned, there is limited prior experience on which to call. Therefore the understanding of what it will take and what to expect is incomplete and/or contains a high degree of uncertainty.*

Factor	Question	Scale		
CULTURE	MULTIPLIER	Low = 1	Medium = 2	High = 3
Behaviors	Is the change consistent with the existing culture? Does it require very different behaviors?	The change is consistent with the existing culture. It does not require a shift in beliefs or assumptions. It does not significantly change behaviors.	The change is largely consistent with the existing culture. Some change in behavior is required, but it is not radical. The change can be accomplished with minor change in underlying beliefs and assumptions	The change demands a significant shift in culture. No only are there new behaviors, but it also requires people to adopt new beliefs and assumptions.
Routine	How different in the daily work for those impacted?	For the majority of people impacted, the change is a small shift in their daily activity. They do the same living with limited changes or additions.	For the majority of people impacted, the change is a moderate shift in their daily activity. A significant part of what they do is different.	For the majority of people impacted, the change is a significant shift in their daily activity. They will see the impact every day and their roles are different.
Restructuring	Is there restructuring of the social or organizational fabric?	The change will require little or no change in the organizational or social structure or power distribution.	The change will require some change in the organizational or social structure or power distribution. This is in the form of additions and minor shifts in the structure.	The change will require a new or significantly changed organizational or social structure or power distribution.

These axes can be combined by the simple convention of multiplying the two factors together as is shown in the Equation 5.

$$\text{Challenge Level} = (\text{Adoption Difficulty} * \text{Solution Difficulty}) \quad (5)$$

However, plotting this data by generating data from a 27 level-two factor design generates the contour and 3D surface plots are shown in Figures 2.3 and 2.4. This formulation however makes a large volume for the lower challenge levels. Counter intuitively, this formulation assigns the same challenge level with items that have a very low adoption difficulty, but a high design difficulty, and vice versa. Comparing that to the real world, however, does not ring true with experience. One cannot assume, for example, that low design difficulty will automatically mean epidemic adoption and thus the challenge level to be the same for low and high adoption difficulties. Testing this formulation with real live examples, points to the inadequacy of this simple representation of overall challenge level. If the challenge level itself is to have some comparative meeting a new formulation for it must be determined from the semi quantitative factors we have developed for adoption and design difficulties.

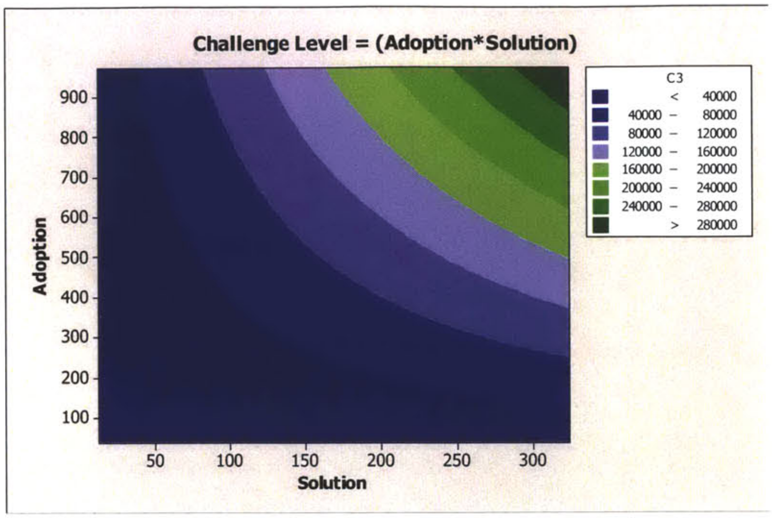


Figure 2.3: Contour plot of simple multiplication of Adoption and Solution Difficulty

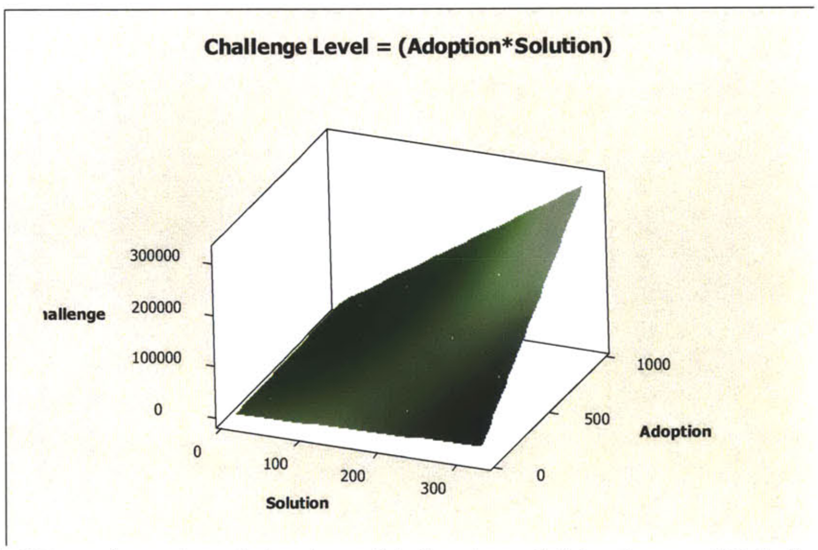


Figure 2.4: 3D surface plot of simple multiplication of Adoption and Solution Difficulty

By generating multiple data sets with a 2^{27} full factorial design, we were able to test multiple formulations for the overall challenge level based on the semi quantitative factors. At the end the formulation that fits our needs the best was the one represented in Equation 6.

$$Challenge\ Level = \ln(Adoption\ Difficulty * Solution\ Difficulty) - 6 \quad (6)$$

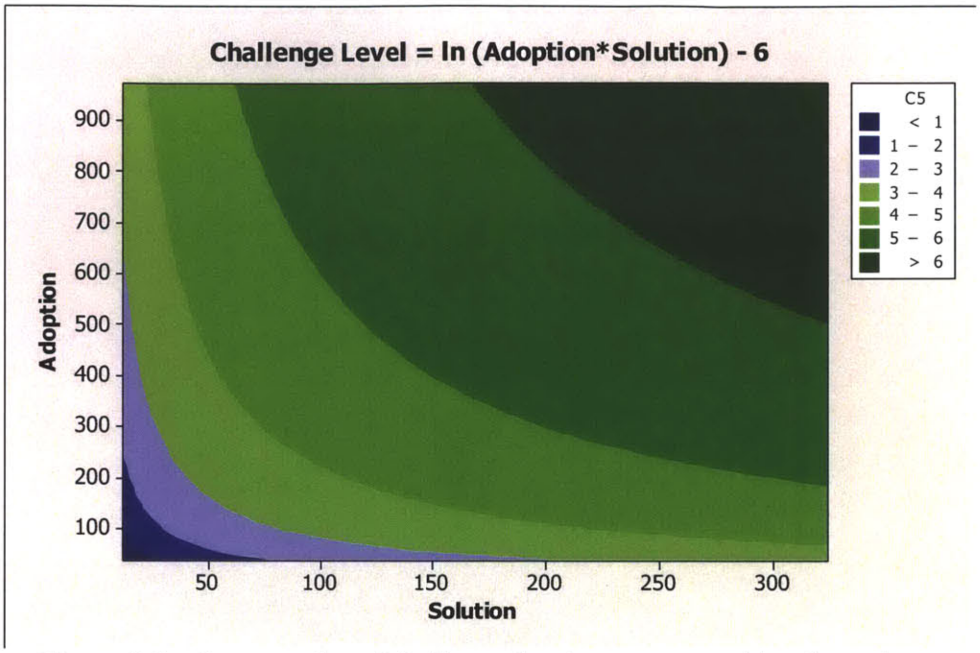


Figure 2.5: Contour plot of challenge level using natural log formulation

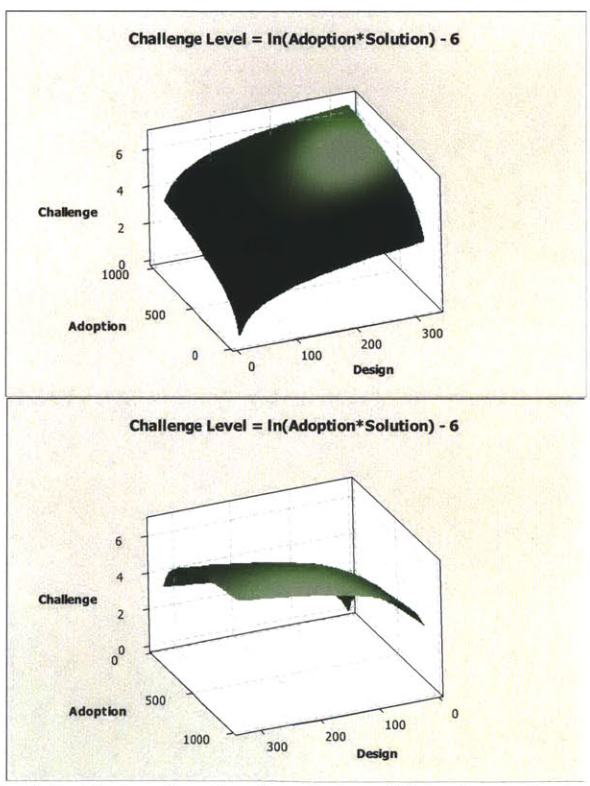


Figure 2.6: 3D plot of challenge level using natural log formulation for challenge level.

Equation 6 has many advantages. As shown in the contour plot of Figure 2.5, we can neatly divide the challenge level in six zones the relative numbers of which have appropriate and intuitively correct areas for each. Areas with either low adoption or solution difficulty levels are not arbitrarily assigned a low challenge level. On the contrary, characterization is classified by area. There are very few zones where low challenge levels attributed without valid factored reasons. Figure 2.6 shows the 3-D plots viewed from two different angles of the surface of the challenge level using this natural log formulation. As we progress through the rest of this paper this is the formulation we will adopt. It will allow us to assess a multitude of human endeavors through the semi quantitative factors and place them on the contour plot of challenge level. We can then make some general, inductive conclusions about the challenge levels and the endeavors that they contain. A priori, we will assume that our interests will primarily reside in those endeavors that occupy the zone in the diagram that has challenge levels above six. These are the endeavors that we will call the most challenging human endeavors.

SECTION 3: DEFINING THE OPTIMAL/NECESSARY CONDITIONS FOR SUCCESS IN THE MOST CHALLENGING ENDEAVORS

Defining optimal and necessary conditions for success exhibits a multitude of paths for accomplishment. We chose the most exhaustive pathway so as not to commit the sin of omission, and this was to amass datasets from the following two main sources: a critical study of all change related research (Giffin, 2007) and a bibliographic study of all recent management scientists (Podsakoff et al, 2008) that are the most cited and relevant for our question around driving design or adoption of complex socio-technical systems and changes. The Podsakoff study naturally links to some more classical thinkers going back to the annals of the history of philosophy and metaphysical and moral studies, which yield some significant insights. In studying these sources, we can search for those factors and common characteristics needed for success in the most challenging human endeavors. The idea is that we would be able to converge through a process of syntactic analysis to a set of critical view factors that are common for these situations. Commonality of these factors would then point to through inductive reasoning to the initial hypothesis that **all** of these factors are necessary for success in the most challenging human endeavors; this hypothesis can then be tested empirically against historical cases.

Both these datasets were parsed and the process of affinitizing and grouping that one may normally do as a part of organizing free flowing customer insights data during product development (Hale, 2010). The KJ (Kawakita Jiro) method was utilized to organize the various inputs. This process allowed us to organize massive amounts of qualitative data, where the statements are numerous and/or complex, the information lacks a lot of consistent or imposed structure, and where statistical processing and summarization techniques are not appropriate. We began with raw data and grouped them by similar content. Grouped data was put into a flow-down structure called the "ladder of abstraction", a rational tree of related statements shown in Figure 8. The structure of interrelated data is ranked in importance to meeting the objective of the study. The process is iterative and starts with creating initial category buckets for analysis and refining them through a Bayesian approach with additional information. In other words, the initial hypothesis (H) of the critical factors are initially formulated based on an initial set of evidence (E). As the evidence is grown from the dataset, the probability of any new or refined hypothesis is assessed qualitatively. This process of Bayesian induction is embodied in the Bayes theorem shown in Equation 7.

$$P(H_i|E) = \frac{P(E|H_i)P(H_i)}{\sum_{1}^{N} P(E|H_i)P(H_i)} \quad (7)$$

The trick is to interactively update the factor list of the hypothesis given new evidence and prior knowledge as it grows.

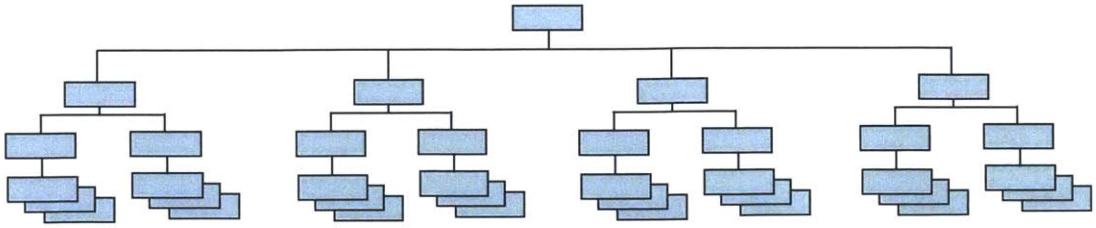


Figure 3.1: Ladder of abstraction where individual data and observations can be grouped under large themes and minimum set of factors at the top of the tree.

Mechanically this process writes down on Post-It™ notes, or virtually on a mind map creation tool, clarifying and understanding the detailed facts and grouping similar detailed facts – a step often referred to as "affinity grouping" (Creveling, 1997). With each round, the detailed facts are grouped and titled. This process was repeated for the complete dataset over the course of two years across the total dataset. The process is shown pictorially in Figure 3.1 and 3.2.

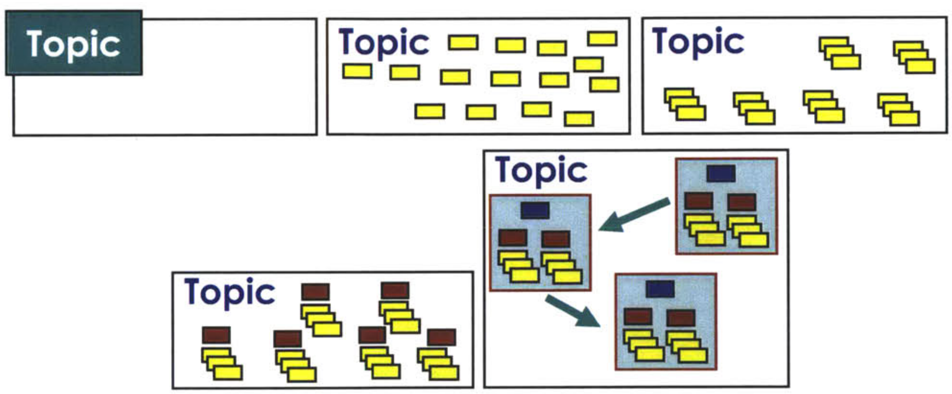


Figure 3.2: Creation of the critical success factors and conditions for the most challenging human endeavors (adapted from Creveling, 1997).

In accounting for the second dataset of management literature, we quickly discover that management science is a very complex and multi-faceted enterprise. The body of knowledge has grown over time in a highly non-linear and cross-referential manner, with key thought leaders currying favor and shaping the landscape of the field. It is hard to parse the body of knowledge into any highly specific taxonomy—any attempt to do so leaves much to be desired. However, it is important to take an initial stab at generating an essential list of management science areas of knowledge, beginning with some (admittedly inadequate) classification scheme for the sole purpose of bringing order to this intellectual chaos before delving into those frameworks that provide us the most value in terms of being able to define the necessary and optimal conditions for success in difficult human endeavors.

With this in mind, we have chosen the following scheme: major management science knowledge area parsed to major thought leader or synthesizer parsed to title of the big idea. Most management theories have two portions. The first is the **descriptive** and **predictive** portion (the part that accounts for a set of real world observations made in the past and allows one to forecast the future based on a set of circumstances) (Beinhocker, 2008). The second is the **prescriptive** portion (the part that lays out some implications, principles and courses of action that individuals can and should take based on the theory presented) (Rechtin et al, 2000).

For example: "Empirical cognitive studies have shown that the human mind can most effectively remember 6-8 bits of information, and more than this leads to confusion and significant losses due to mental switching. (descriptive and predictive portion) When organizing teams, parsing strategic projects, stating principles, listing values, or any other such useful category of human endeavor, it is always best to try to keep to within 6-8 elements. (prescriptive portions)." We have found that management theories fall somewhat neatly into a four-box grid (individual vs. organization on one axis and inwardly-oriented vs. outwardly oriented on the other axis) This is shown in Table 3.1.

Table 3.1: Model for categorizing all management science theories

		DESCRIPTION-PREDICTION	
		INDIVIDUAL-FOCUSED	ORGANIZATIONAL-FOCUSED
PRESCRIPTION	INWARDLY-ORIENTED	Theories with individual descriptions & predictions for inwardly-oriented prescriptions. (e.g. Csikszentmihalyi's flow theory of happiness)	Theories with organizational descriptions & predictions for inwardly-oriented prescriptions. (e.g. Hammer's business process re-engineering)
	OUTWARDLY-ORIENTE	Theories with individual descriptions & predictions for outwardly-oriented prescriptions. (e.g. Blanchard's situational leadership model)	Theories with organizational descriptions & predictions for outwardly-oriented prescriptions. (e.g. Porter's 5 forces analysis)

The example above would fall into quadrant 3 (the lower left hand corner using Cartesian convention). The description and predictions are for an individual (or born of the study of individuals) and the prescriptive guidance is outwardly oriented, that is actions individuals can take in organizing the outside world. One can argue it is quadrant 2 (upper left hand corner) if the individual chooses to always keep things they are working on in their minds to 6-8 elements. This model was tested on the following list of management science thinkers in the area of science from Giffin's (Giffin, 2008) study of major changes and their propagation through technical systems shown in Figure 10.

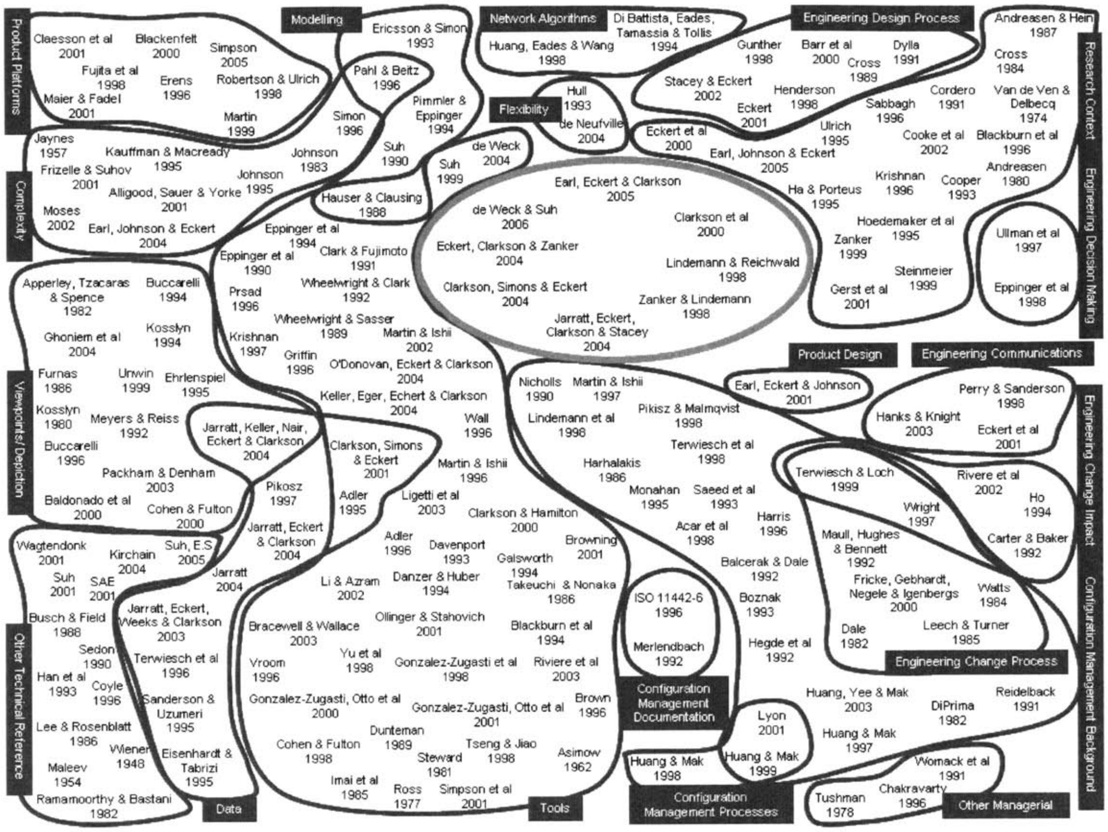


Figure 3.3: Change Propagation Citations from Giffin, 2008.

These buckets were placed into the classification scheme as well along with the Podsakoff bibliographic study which was able to unearth the 150 most cited authors in the field of management science from the years 1981-2004. Some examples from the authors studied and their primary areas of contribution are shown below in Table 3.1. These lists combined with the Giffin list in Figure 10 allowed for the creation of an iterative group of proposed primary attributes for success in the most complex endeavors. This approach was considered the most salient way to get as close to first principles as possible. It should be noted that a significant amount of the authors studied were from the academic arena, however this was not and ubiquitous truth. A significant number of the individual studied were people that had first-hand experience in navigating large changes, and thus took a broader perspective on their personal experiences through some of their writing. The exploration of these same sources in a later section of this writing drives to causal arguments as to why the success conditions and attributes are as they are. One condition is indeed a new hypothesis which is generated from a series of different theories but can be derived and applied in a several situations. The true test of the optimality and necessity of all of these conditions is applying them to those socio-technical challenges that truly are above a 6 or greater as defined in the earlier section.

Table 3.2: A sampling of the 150 management scientists and their theories studied to amass the top conditions

Primary Field of Contribution	**Author**
Strategy	1. Donald Hambrick (strategy) 2. Henry Mintzberg (schools of thought, nature of mgmt and strategy) 3. Sun Tzu (principles for strategy) 4. Kathleen Eisenhardt (strategy as structured chaos)
Project, Program and Portfolio Management	1. Eliyahu Goldratt (constraints) 2. David Allen (getting things done) 3. Robert Cooper (stars, dogs, cash cows, question marks)
Internal Politics, Career Growth, Speaking, Oration and Gravitas	1. Laurence Peter (principles of promotions) 2. Scott Adams (avoiding stupidity) 3. Tom Peters (personal branding) 4. Roger Fisher & William Ury (negotiation)
Manufacturing, Operations, Supply Chain and Quality	1. Taiichi Ohno, Edward Deming, Walter Shewhart, James Womack, Daniel Jones, Joseph Juran, Shigeo Shingo (control and quality in mfg) 2. Charles Fine (clockspeed and supply chain evolution) 3. Charles Babbage, Frederick Taylor, Alfred Sloan, Henry Ford (classical theories) 4. Robert H. Hayes and Steven C. Wheelwright (manufacturing and operations maturity model/product process matrix)
Organizational Behavior, Decision Making, Governance, and Ethics	1. BF Skinner/ Alan Turing (ABC model, behavioral vs. cognitive models) 2. Mihaly Czitszentmihalyi (flow state) 3. Edgar Schein (mental models) 4. Abraham Maslow (hierarchy of needs) 5. Dan Pink (motivation) 6. Jeremy Bentham (utilitarianism), Immanuel Kant (categoricalism), John Locke (categoricalism), John Rawls (categoricalism, veil of ignorance), John Stewart Mills (utilitarianism), Niccolo Machiavelli (pragmatism) 7. Peter Senge, Chris Argyris, Donald Schon (organizational learning) 8. Ken Blanchard (situational leadership) 9. Herbert Simon (organizational anatomy) 10. Marcia Blenko (decision velocity, RAPID)
Learning	1. Reg Revans (L = P+Q) 2. Benjamin Bloom (taxonomy)
Change and Adoption	1. Everett Rogers (adoption) 2. Malcolm Gladwell (tipping point) 3. Rob Cross (social and organizational networks) 4. Geoffrey Moore (chasm) 5. Daniel Kahneman (thresholds) 6. John Kotter (change dynamics) 7. Richard Dawkins (memes), 8. V.S. Ramachandran (mirror neurons) 9. Howard Gardner (stories)
Futurism, Marketing, Business Development, and Competition	1. Michael Porter (5 forces) 2. Clayton Christensen (disruption, the S-curve) 3. Adam Brandenburger (co-opetition) 4. C.K. Pralahad, Gary Hamel (competing for the future) 5. George Whitesides (biosystems)
Systems, Complexity, Technology, and Organizational Theory	1. Charles Darwin/Jean Baptiste Lamarck (evolution algorithm and inheritance DNA and non-DNA based) 2. Richard Nelson (classification of technologies)

	3. Jay Forrester/Peter Senge (system dynamics) 4. Tom Allen (organizations in technological organizations) 5. Jay Galbraith (organizational design)
Enterprise Process and Structure	1. Michael Hammer (business process engineering)
Innovation and Design	1. Noriaki Kano (preferences) 2. Eric von Hippel (user centered innovation)
Philosophy, Mathematics, Epistemology and Metaphysics	1. Socrates 2. Plato 3. Aristotle 4. Borges 5. Kurt Gödel

This analysis allows us to reflect the proposed necessary conditions in our grid of Table 3.2. This is shown in the Table 3.3 below.

		DESCRIPTION-PREDICTION	
		INDIVIDUAL-FOCUSED	ORGANIZATIONAL-FOCUSED
PRESCRIPTION	INWARDLY-ORIENTED	7. Intrinsically motivated brilliant or dedicated resources with adequate resource rate 1. Burning platform and compelling destination	10. Visualization of information, interdependencies, status, monitoring 11. Segregation of decisions and actions by time cycles 9. Ideas good or bad get transmitted without variation 4. Six to nine key players
	OUTWARDLY-ORIENTED	2. Single visionary who creates and evangelizes system-level design 6. Abandon false paths, maintain true north	3. Understands and balances technical and moral implications 5. Relationship with the world is like a campaign or movement 8. Deploying prioritized, globalized resources while aggregating, synthesizing local innovation

Table 3.3: The necessary conditions for success in the most challenging human endeavors mapped to the management science theory grid.

These attributes are discussed in great detail in the next section. These 11 conditions can be laid out in a logical format that is more cognitively accessible than how they're laid out in the grid of Table 3.1. The taxonomy of Table 3.3 is valuable to us because it allows us to efficiently mine, a large data set of management science and change theory. However, as a means of communicating the underlying connections between the 11 hypothesized necessary conditions for success it proves somewhat lacking. In order to better present the outcomes of the analysis we have chosen to use the golden circle representation of Simon Sinek, which helps us follow a more logical and impactful way of representing the 11 conditions. Sinek uses what is called the Golden Circle illustrated below as a means of rightful explaining and inspiring people around a construct. The Golden Circle starts with WHY, then moves to HOW and then gets to the tangible

WHAT (Sinek, 2009). In looking at the conditions above, we see two major WHYs. The first is leading the system from a burning platform to a compelling destination and the second is abandoning false paths while maintaining a true North. If these are the two WHYs, we can build the HOWs and the WHATs from these two stories and then link all of these necessary conditions underneath one composite interrelated set of stories. That story would read as the following:

> *The existence of a burning platform and a compelling destination affords the opportunity for single visionary leader-system architect to create and evangelize a system-level design across all beneficiaries. The leader/architect understands and balances the technical and moral implications and seeks counsel, support, convergent and divergent ideas from a core group of 6 to 9 key players and together, this core group's relationship with the outside world is like a campaign or a movement. The larger ecosystem in which the single visionary leader and the 6 to 9 core players sit allows them to abandon false paths on their journey from the burning platform to the compelling destination. They are enabled by intrinsically motivated and brilliant or extremely dedicated people resources with a sufficiently rich resource rate in the larger organizational system. This allows for the deployment of prioritized and globalized resources while at the same time enabling the aggregation and synthesis of local innovations. This is accomplished by having ideas good or bad be transmitted with minor variation, which necessitates the need for the creation of tools that allow for the visualization of information, interdependencies, status, and monitoring of ongoing progress. This all results in system-level segregation of decisions and actions by the appropriate time cycles in which these decisions and actions need to be made and taken.*

Let us break down each of these conditions in the next section and explore them with some imaginative examples.

SECTION 4: EXPLANATION OF THE NECESSARY CONDITIONS FOR SUCCESS

After an exhaustive empirical study of all aspects of socio-technical systems and how they are designed and deployed, table 3.3 shows the 11 presumed necessary conditions for success in the most challenging human endeavors. Each one of these categories is a multiplex of a variety of different attributes that follow a common theme and are held together by fundamental causal reasons. It is important to describe each one of them in a high level of detail.

CONDITION 1: Burning platform and compelling destination:
This condition posits that in order for human beings to commit to changes, there must be two necessary images clearly articulated and understood by the population. The first is a **burning platform**. The burning platform refers to a compelling reason that just cannot be denied to move away from the status quo and the current condition. The term comes from the idea of an oil platform or an oil rig that is on fire and about to explode. The occupants and workers on the oil rig have no other choice but to jump into the cold waters that surround the oil rig because staying on the rig itself means certain death and demise. The status quo is so uncomfortable and wrought with danger that the occupants must move from where they're standing even if it means jumping into another condition of uncertainty that is jumping into the ocean.

Figure 4.1: Images of a burning platform and compelling destination (taken with permission from www.2020visions.wordpress.com and www.favim.com)

The image of a burning platform is particularly powerful because there is no way that an occupant of an oil rig can deny the dire situation in which he or she finds himself when a platform is burning (Conner, 1996). There is no question or disbelief about the danger of staying in the status quo. Rather, the need to move from the current position is incredibly clear and undeniable. This condition existing when a large change needs to be undertaken in a socio-technical system is vital. If there is not a population that does not believe that the status quo needs not be changed, then no change can truly happen. While often emergent changes can happen without the need of a burning platform, the most challenging changes absolutely cannot. The concept of belief is also an important one. If individuals in question have internalized the danger of the status quo, then only can they and thus have tremendous impetus for moving from it.

The compelling destination is often referred to as the vision of the future state. This is a much more positive construction than the burning platform but provides the pull where the burning platform provides the push. This is a clearly articulated view of a compelling future that people can find themselves in. It is a place where people would want to go and have an overwhelming desire to create and achieve. If the burning platform is danger, then the compelling destination is safety, warmth and happiness. The question of belief is as important to the compelling destination as it is the burning platform. If people are not able to have a clear and crisp articulation of what the future vision would look like and how it can be better from the status quo then movement also will not happen. And within that believable existence of the compelling destination, what is the most more important is the constituencies involved seeing themselves and those that they care about in that future vision. Inclusion of the individual and his loved ones in the compelling destination is a necessary condition for creating a successful one (Gardner et al, 1996).

CONDITION 2: Single visionary who creates and evangelizes system-level design.
This particular condition may be viewed as one of the most controversial of all of the conditions that are hypothesized. However, out of the near 200 sources and theories reviewed around leadership, the common theme of having a single visionary leader was too prominent to pass up. Whether it was Margaret Mead and the drive to chronicle the cultures of the world (demonstrating that none are superior) or Robert J Oppenheimer and his major role in the creation of nuclear physics and the nuclear bomb, the existence of a single visionary who has a holistic architecture of the design and required adoption seems to be one of the most necessary conditions. This concept of the single visionary leader supersedes whether the system is a social or technical one. We find visionary leaders present from all walks of life in taking a deep dive into all of these areas and types of leadership.

The list is long—from Robert Maynard Hutchins, a visionary around education, to Alfred P Sloan, an automotive genius, to Martin Luther King Jr. and Mahatma Gandhi, important figures in driving civil and social change. We see individuals like Eleanor Roosevelt and Margaret Thatcher and even Pope John XXIII, who expounds that Catholics and Christians must return to the simple teachings of Christ and avoid bureaucratic and political infighting. In examining one of the socio-technical systems we will be studying later, we find the embodiment of single visionary leadership present in the work at the Manhattan project. The success of Los Alamos rested largely on its teamwork and the leadership of director Oppenheimer. Oppenheimer understood that as the director of the laboratory, it was not his job to make deep technical contributions, although he was well capable of doing such. Rather, it was his job to make all of the brilliant resources talked about in the previous condition work together and to understand all the technical work that was going on, to make it fit together and to make decisions between various lines of development. Very few in history have performed these functions as brilliantly as Oppenheimer.

Figure 4.2: Three distinct examples of single visionary leaders: Margaret Mead, Martin Luther King, Jr. and Robert J. Oppenheimer (Gardner, 1996).

The maximum potential of any system is assured if and only if the full intent of the system is understood in the mind of a single individual. It is best if this individual is indeed the system architect, and has an ability and mandate to transmit this understanding to others involved in designing, building and operating the system. When there is a preponderance of architects, each with her own portion of the true intent, achieving the maximum potential of any system is impossible. It is through the mouth of the single visionary, that the burning platform and compelling destination are articulated with vigor and fervor.

CONDITION 3: Understands and balances technical and moral implications:
When we carefully examine the single visionary leaders mentioned in the above section, we notice a very distinct pattern that repeats itself again and again. The leaders were masterful at their area of expertise and their technical knowledge of the system that they were trying to influence, be it Oppenheimer's expertise as a nuclear physicist, Margaret Mead's deep understanding of anthropology and psychology, or Martin Luther King's command of law, civics, religion, and history. These singular leaders could be removed from the history that they were driving and be viewed through solely through the lens of being a subject matter expert in their field, and on this basis alone they would receive the highest global recognition. This deep technical understanding of their area is a critical

component in describing Condition #3. On the flipside, Oppenheimer, Mead and Dr. King in their place in history all had a hand in being deeply involved in large moral debates of the day. Oppenheimer was looking at the difference between achieving peace through violence and pain that was of a short contained duration or allowing mass pain to persist for many, many years. Mead was dealing with the implications of balancing scientific findings and beginning a new way of looking at cultural and societal differences and how people view superiority and inferiority amongst races. And Dr. King dealt with the issues of equality, justice and peace during a time of tremendous tumult and unrest and he had several choices that he had to make in doing this.

For all of the singular leaders that were studied as a part of this work, the conflict between categorical moral values and utilitarianism was clearly apparent. In the categorical side, the leaders were faced with certain elements of their choices that they viewed as either categorically wrong or categorically right and had no chance of being violated. For Dr. King the principle of nonviolence and equality amongst humans were two of the categorical principles that he was not willing to violate. For Dr. Mead, her insistence that the science shows that cultural diversity does not indicate inferiority or superiority was at the center of her categorical principles and in many ways drove her science. And for Dr. Oppenheimer, the idea that the deaths of millions and millions of people needed to be ended, even if it meant the deliberate sacrifice of a small group of people. In looking at the categorical elements of the moral situations that the singular leaders face, we find that they also have to balance those broad-brush dogmatic values with a certain degree of utilitarianism.

In accomplishing their goals, the pragmatic elements of their personalities were shown to be rather more effective and each clearly engaged in some level of tactical moral pragmatism. The reason they were able to do this is only due to their deep-rooted fundamental understanding of the systems that they were trying to influence and change. Without this nuanced knowledge of the world and their subject matter, there was no hope for these leaders to navigate the complex choices that they would have to make in order to be successful.

And thus it is the presence of these three elements—a fundamental set of principles that are truly categorically right or wrong, a measure of deep technical expertise and understanding of the system that they're trying to change and influence—which then allow for the singular visionary leader to make what could be perceived as pragmatic or utilitarian moral decisions along the path to accomplishing the greater goal.

It is a person so able to balance the technical, moral and social implications who establishes the need for a new term: **the Leader-Architect**.

In order to describe this delicate balance that a Leader-Architect plays, we present an interview with a global Leader-Architect involved in the formulation of two important world-changing concepts. These are the Culture of Peace and UN Resolution 1325, both of which provide revolutionary global frameworks for change (Chowdhury, 2012) and is presented in Appendix A.

CONDITION 4: Six to nine key players:
Condition #4 speaks to the observation that in most group-level theories, the optimal number of individuals around a singular leader appears to be on the order of six to nine. This condition dictates that the singular leader must have an opportunity to interact with a core set of people with whom he or she can do two important things. The first is the support either in the honing of ideas or in the elimination of candidate ideas and thus providing moral support. The second is in the accomplishment of the work and interfacing with logically organized communities outside of the group of six or nine, and thus providing internal and external benefits at the community level.

Figure 4.3: No more than 6-9 key players around the singular visionary leader.

CONDITION 5: Relationship with the world is like a campaign or movement
In our study of system architecture we have come to appreciate the critical role of the operator or intelligent agent. In most all cases, the architect assumes a certain range of behaviors for these human agents that need be predictable or to which the system is robust to uncertainty. In many cases, we have instances where the primary operand is a human or intelligent being. For instance, the Saturn V rocket architecture dealt with the primary operand as the human astronaut. In manufacturing systems, recent studies have shown that the human machine operates at about a 2.3 sigma capability (Bouchard, 2010). The elimination of human errors is a very important part of lean manufacturing systems. Lean systems use items such as visual controls, intuitive plant layouts, and "poka-yoke"systems that are error proof (Wally, 2009). The architecture of the system incorporates and drives the behavior from the human agents that are required for success of the system; that is, robust, high quality products made just as the customer needs them in the right quantity at the right time. In cybernetics, the control of the man-machine interface is of primary concern, in as much that cybernetics studies the interaction of the man with the machine as a part of a large regulatory system (Heylighen, 1999). In system dynamics, the ability to model the human preconceived mental models that lead to endogenous operating policies is at the center of the practice (Sterman, 2000).

Kurt Lewin, considered by many to be the founder of social psychology, laid out the field theory of behavior, which we will put to use in our journey to develop the prescriptive version of the principle. Lewin stated that human behavior (B) is a function of both the person (P) and his or her environments (E), in other words:

$$B = f(P,E) \quad (8)$$

Thus, human behavior is determined by the total field of an individual's situation, which Lewin called "the totality of coexisting factors which are conceived of as mutually interdependent (Hudson, 2009). This has incredible implications for architecting of systems. If behavior of the human agent is vital to system success, and human behavior is both a function of individual mental states and environment, then the design of the architecture must some how account for or be amenable to driving certain intended or required behaviors of the human agents in that system. But is this not tantamount to mind control? And is this possible? Indeed, psychology says it is. The ABC model of behavior is based on the operant conditioning paradigm of psychologist BF Skinner (Skinner, 1974). The ABC model states that manipulating either the conditions preceding the behavior or the consequences of following the behavior may change the behavior. Behavior that is rewarded will occur more often while behavior that is not, or is punished, will occur less frequently. This is a basic assumption of clinical and educational psychologists operating behavior modifications programs and should also be for system architects. Thus it is important to build design factors into the architecture of the system governing policy structures, rules, and processes that actually reinforce the required or necessary behaviors for system functionality through positive reinforcement. This can now be expressed in the prescriptive version of the principle:

The most challenging socio-technical system architectures should incorporate purposeful policies, processes and business rules such that the behavior required of human agents for robust system functionality and adoption are reinforced through explicit antecedents and positive consequences.

If this is the case, the best way to think about the way the socio-technical Leader-Architect and his/her 6-9 person crew must interact with the world is as if they are conducting a persuasive campaign, swaying individuals and support and pulling early adopters into the mix and pulling talent underneath them. And as with all campaigns the degree of success can be measured by the Net Promoter Index or NPI, and conceptually this is exactly idea that must be built into the system architecture so that it itself reinforces its own propagation.

The second very important part of this design as a campaign mindset is the understanding and condition that the best designs are those that are functional and beautiful for the beneficiary. They are "elegant". We discussing this, we start with two lemmata:

> *Lemma 1: There is no absolute measurement of elegance (combined functionality and beauty), but there are required attributes for something to be considered elegant.*

Lemma 2: Every stakeholder (including the Leader-Architect) of the socio-technical system has a unique definition for elegance.

The concept of elegance (a combination of beauty and functionality) has arisen in many fields of human endeavor. In mathematics, there has been a long-standing drive to understand what makes mathematical solutions beautiful and if there is a universal definition of such. Bertrand Russell argued that mathematics contains not only truth but supreme beauty more than the finest art (Russell, 1919). In mathematics, an elegant proof is thought of generally as that which has minimal assumptions, is succinct, is surprising, contains new and original insights and is broadly applicable to many problems.

In building architecture, aesthetics and elegance usually have an association with rhythm and purposeful symmetry. Yael Reisner, architectural historian, claims that an architect who suppresses his or her own ideas about elegance is insulting all other stakeholders in the process and has denied the world of something new and original in the way of beauty and functionality (Reisner, 2010). This brings us to the question of what makes something beautiful. Functionality is objectively definable and clear to measure. However, it is when functionality must be combined with beauty where the lack of definable and measurable beauty becomes problematic.

Matthew Collings, art historian, has attempted to tackle the question of the universality of beauty through an examination of what makes his own personal top ten works of art beautiful, looking for patterns (Collings, 2009). His conclusion is simply each person should look at their own top ten favorite works of art and look for what they think their personal themes are. Thus, beauty in Collings' estimation is a combination of individuality and universality.

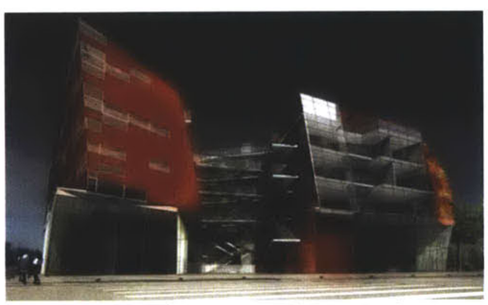


Figure 4.4: Odile Decq architectural concept from Architecture and Beauty. C. 2010.

For example, a piece of art is beautiful that appeals to some childhood memory or emotion of the observer, but of course each person's childhood memories are somewhat unique and individual.

Lastly, neuroscience and art are combining in a new domain called neuroesthetics. Neuroesthetics seeks to find the brain functions and mental states at a neurological level that explain or are involved with a person finding a piece of art beautiful or aesthetically pleasing (Costandi, 2008). Once again, this field of study defines certain universal requirements for beauty but leaves open the opportunity for individuals to define and the specifics.

The architect must make every effort to deliver an elegant architecture by understanding what elements contribute to elegance by studying each stakeholder's specific attitudes on beauty of the system. This becomes increasingly important as the challenge level of the system itself begins to grow as defined by our challenge level definition before.

CONDITION 6: Abandon false paths, but maintain true North

This particular condition is one that will be incredibly familiar to all scientists (be they natural or social). The scientific method itself is involved with deep observation of the situation, collecting those observations to formulate some hypothesis that describes the situation, and then provides a framework that can be proven or disproven through experimental data. In the absence of this experimental data, the discipline of the scientific method forces individuals to abandon false paths quickly, or in the timeframe that is quick in relation to the topic being studied, days in the case of chemistry and say decades in the case of geology.

Indeed, in design as well as in the propagation of a socio-technical system the same holds true, but as in science, must strike the perfect balance between incredibly tenacious and not giving up on an idea versus being strict and disciplined about abandoning false hypotheses when the data starkly leads one to do that. It is important therefore that the group crafting the socio-technical system be completely aware of all of the necessary truths and observations that must be well understood by all parties involved so that at the nearest false paths can be abandoned in a systematic and data-driven manner. A further nuance to this principle condition can be added: often it is the abandonment of small paths while the dogged determination to stay on the larger path remains intact that is important. Using the Manhattan Project as an example, the larger goal of creating the first nuclear weapon existed on a large scale throughout the project because the hypothesis existed that it could be done. But within that larger goal, on a day-to-day basis, smaller hypotheses were assessed and abandoned as necessary in a factual manner. So perhaps it is the combination of dogged determination for the large goal, a seemingly insurmountable task and tremendous conservatism and frugality for smaller goals and being somewhat skeptical or pessimistic at the local level that is at the heart of Condition #6. This is a more data driven and quantitative build on Condition #3.

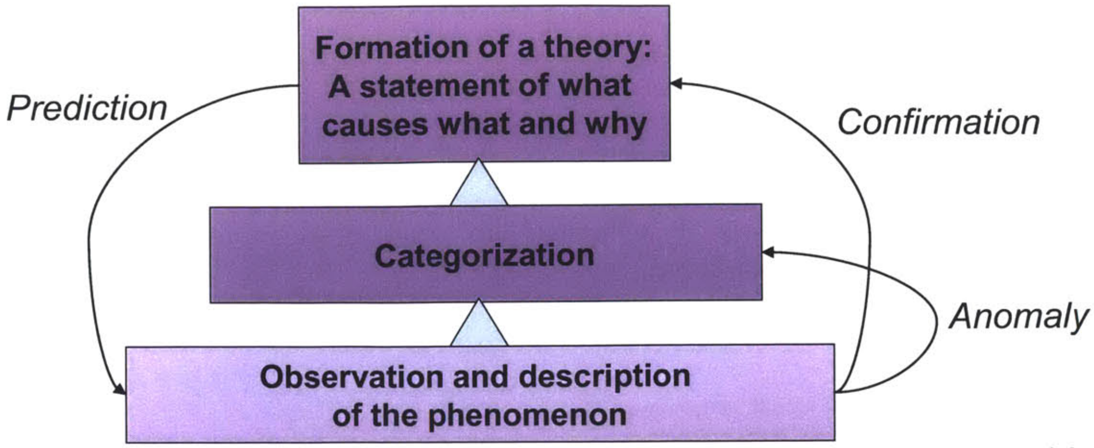


Figure 4.5: The basic ability to observe, categorize and move forward or abandon false paths is a critical part of Condition #6. (Christensen,2003)

CONDITION 7: Intrinsically motivated brilliant or dedicated resources with adequate resource rate:

Nothing gets accomplished without the right resources at hand. These resources could be financial, people or capital, and equipment. Regardless of the type, the presence of resources is a fundamental part of accomplishing any endeavor. In this particular condition however, we refer first to the presence of people resources. Those that are intrinsically motivated, as well as have the appropriate skill and intelligence level to get the most difficult things accomplished. There are two types of motivation as described by behavioral psychologists. The first is extrinsic motivation, can be described as things we do for basic survival. For instance, working at a job to get paid is something that is usually in the category of extrinsic motivation. It is a common hypothesis amongst social scientists that tremendous accomplishments and great passion does not come from extrinsic motivation alone. Intrinsic motivation is the type where, even if the individual were not getting paid, they would choose to do that activity on their own. This is where true passion and devotion and dedication come from is a finding in many of the sources cited in the previous section that intrinsic motivation is associated with individuals who accomplished tremendous levels of complicated design work as well as driving adoption in many areas across many populations. Intrinsically motivated workers do what they're doing because they love it. They could not see themselves doing anything different. And they are driven by an inner motivation that is far and above anything that payment, the avoidance of pain, the difference of risk, or the elation of security could replace.

Intrinsic motivation and activity is something that cannot be taught. It must be sought out, screened for and then enhanced by the person's environment. Brilliance in a particular area can also be screened for, but it is something given the proper talents and skills can be acquired and taught if the individual has a high level of intrinsic motivation. Intrinsic motivation becomes particularly important when solving the most complex problems needing innovation and creativity. It becomes less important when the task at hand is more wrote, and repetitive. In this way, the extrinsic motivation ("I must do this otherwise I will get fired") and intrinsic motivation ("This is so exciting, I love doing this") becomes the analog to burning platforms and compelling destinations, but much more internally oriented.

The resource rate part of this condition is an important governor to the overall availability of this type of resource. There is a belief that there is a particular amount of time that is required and practice that is necessary in order for some resource to achieve a level of mastery in a particular skill or competency. This competency level, which one could say approaches brilliance the more experience and practice that an individual has, can be measured by how effective an individual is at navigating the most complex and difficult parts of his or her craft. There is a hypothesis called the 10,000-hour rule, which states that a length of a minimum of 10,000 hours of practice in the craft is necessary to become an expert. Being an expert, one can say, is a prerequisite to being brilliant (Ericsson, 2006). Alternately, expertise is qualified with respect to a particular skill set while there are people who are inherently brilliant and apply their unique intelligence across many fields like a polymath. It is the honing of this unique intelligence towards systems-level work through practice and repeated application that needs to accomplished. We can take this a step further and state that this second condition hypothesizes that socio-technical system architecture is itself a craft as much as it is a science. With this, the literature leads us to posit some lemmas:

Lemma 1: Crafts require skilled work and judgment.

Lemma 2: Skill at a craft requires the transfer of tacit knowledge that resides and grows throughout the life of a profession.

Lemma 3: Not all tacit knowledge can be made explicit or written down.

Lemma 4: The practice of socio-technical system architecting has a high tacit knowledge component.

Crafts are those special areas of practice or profession that require a specific skill to be developed through the repeated trial and error of work. As this trial and error occurs, the less experienced in the craft learns and is able to incorporate lessons into future endeavors. Through this process he or she grows his or her skill level and judgment in the profession. As early as the Middle Ages, many professions had special relationships built to help guide this learning process. In most cases, this took the form of mentor and apprentices (Jacoby, 2010). Tailors, bakers, carpenters, and even artists had schools for professions, which included the role of teacher and protégé as incredibly important and central to the long-term expansion of the craft (Chang, 2010). The underlying reason for this is that a skill has tacit and explicit components. Explicit knowledge is contained in things like solution manuals, operations procedures, patent literature and drawings. Tacit knowledge in a craft, on the other hand, is related to know-how, images, patterns stored in the master's head, intuition and heuristics. In domains where the tacit-to-explicit ratios are high, it has been empirically shown that the mentor-apprentice model proves incredibly effective. The mentor is able to shape and structure the experiences of the apprentice and help the individual put their successes and failures in context. An inexperienced resource must seek to be an apprentice of an experienced architect. An experienced architect must take it upon him/herself to mentor an apprentice in order to progress the craft of building the socio-technical system in question. In many cases as we will see, the availability of the brilliant, intrinsically motivated resources at the right resources rate (i.e. one that accounts for the need to develop and carry on a surrogate apprenticeship if needed) is important.

Figure 4.6: Apprentice. Man and boy making shoes. C. 1914, Repro. of painting by Louis Emile Adan (1839-1937).

CONDITION 8: Deploying prioritized, globalized resources while aggregating, synthesizing local innovation

We must not forget the non-people parts of the resource rate. Adequate funding, availability of equipment and even the resource of time distribution is very important. One major issue that is frequently seen with trying to overcome large socio-technical challenges is the disaggregation of resources. Even in our modern world today, we see increasingly disparate groups in disparate locations trying to accomplish common goals. Largely, the issue with disaggregated resources is the failure to achieve high economies of scale and deploy adequate funding to the most impactful on highest priority actions. A small example of this is the existence of several charity groups dedicated to serving underprivileged children. Often a quick study shows that many of these groups exist within one city. However, many of these groups are seeking the same outcomes, for instance, providing children with clean clothes, adequate shelter, or the proper education. An ability to somehow coordinate efforts across these disaggregated groups, particularly in places where they're trying to achieve the same ends would, in the long run, achieve a much more impactful outcome.

Opponents to this type of philosophy would argue that this is a form of standardization that would drive creativity and innovation out of the system, and would greatly dampen inventions that could come from one small group that would have disproportionate impact to the broader population for the better. By creating a one-size-fits-all aggregated scenario, opponents would argue that pooling of resources and standardization would only drive incremental and evolutionary change versus the often revolutionary change that can come from spontaneous innovation. For the purposes of our challenge, we must look at which one of these options provides the adequate resource rate and the adequate total resource.

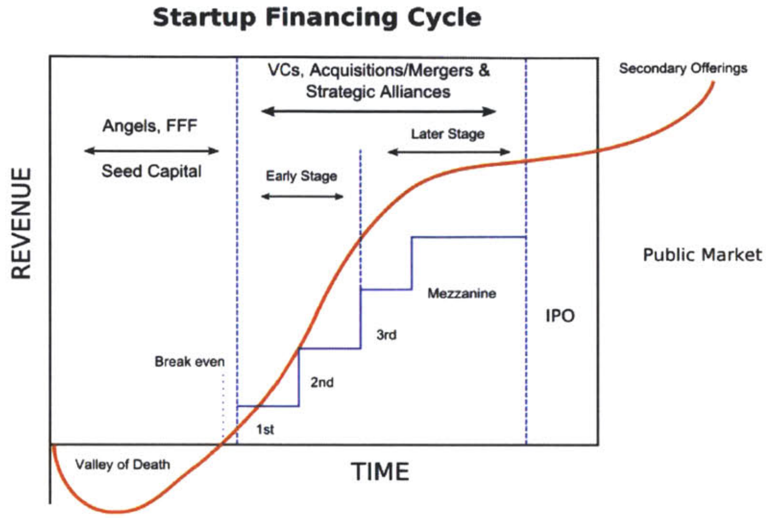


Figure 4.7: A view of the phases that start-ups go through for funding.(Stacey, 2011)

Perhaps the best way to assure both of these things is to find a solution that allows for the benefits of aggregation while maintaining the ability to innovate in small groups in disparate locations. By extending this example of the charities we find a scheme such as the United Way to be perhaps a penultimate solution. The United Way model is one that helps to that helps to pool and then distribute resources and funding to a variety of disaggregated charity efforts. If the donors choose to allow the United Way to make decisions and choices on what to do optimally with their donations, and United Way is able to apply a privatization scheme that most appropriately distributes the resources required at the adequate resource rate to those areas that need them, this can be an effective way to leverage scale. These areas are not consolidated, however, and so they are free to innovate and invent unique solutions that may provide disproportionate positive value in the future if systematized. This ability to drive down prioritized resources while aggregating and systematizing local innovations seems to be a key component of success in socio-technical systems. The United Way model enables the new groups and bodies to navigate their way through the valley of death as is shown in Figure 16. While Figure 4.7 really shows is a commercial startup, but change the revenue y-axis to any other indicator and the pattern is essentially the same.

Conditions #7 and #8 seem somewhat daunting. As uncomfortable as it seems, the combination of different tracks of learning often by luck or social attraction appear together to solve a complex problem completely by random chance or accident. We will find that the next conditions of a unifying leader and the proper organizational conditions must be present in order for the people resources with the right non-people resources is what proactively pulls these items together so that change itself does not have to be merely emergent.

CONDITION 9: Ideas good or bad get transmitted without variation

Sustainable system architectures evolve over time to better fit the environment in which they operate, then influence and change that environment, and eventually change the very attributes the architecture needs to have to fit in its environment.

Co-evolution is a very well known concept in the study of complex systems, be they products or biology. Every system exists within a design space, where multiple attributes can be co-mingled and mixed to produce global performance of that system in its environment (Davies, 2009c). The environment introduces the fitness function that must be solved for and that helps to select amongst a variety of different options (or in the case of architecture, the concepts). Thus concepts, organisms, products are selected from the design space by the fitness function of the environment. At some point, the success of the system will begin to impact the environmental fitness function itself and thus begin a process of different selection criteria. This means that the system (concept, product, and organism) must then either adapt or be less fit for the new environment that it itself helped create. This dynamic can be extended to describe the co-evolution of system architectures and the environment in which they reside. But what is the fundamental unit of system architecture that combines in various forms or formats to create selectable systems?

We have already studied that there are fundamental set of processes required to describe a domain. Turing has done so for computation, Pahl and Beitz have done this for machines and Crawley has done this for system architectures (Crawley, 2010). These are the atomic elements of the system. But likely this level of granularity is too fine to drive a repeatable selection process and co-evolution with the environment. Just like in biology, atoms and molecules are two fine a parsing for selection to act on, and the higher order of genes are required. If genes and the success of the proteins and the systems that are built from those proteins that are selected and thus determine the propagation of the gene in any fitness landscape. an analogous concept is the concept of the meme. A meme, posited by Richard Dawkins, is a unit of human cultural transmission analogous to the gene that allows culture to replicate (Dawkins, 2006).

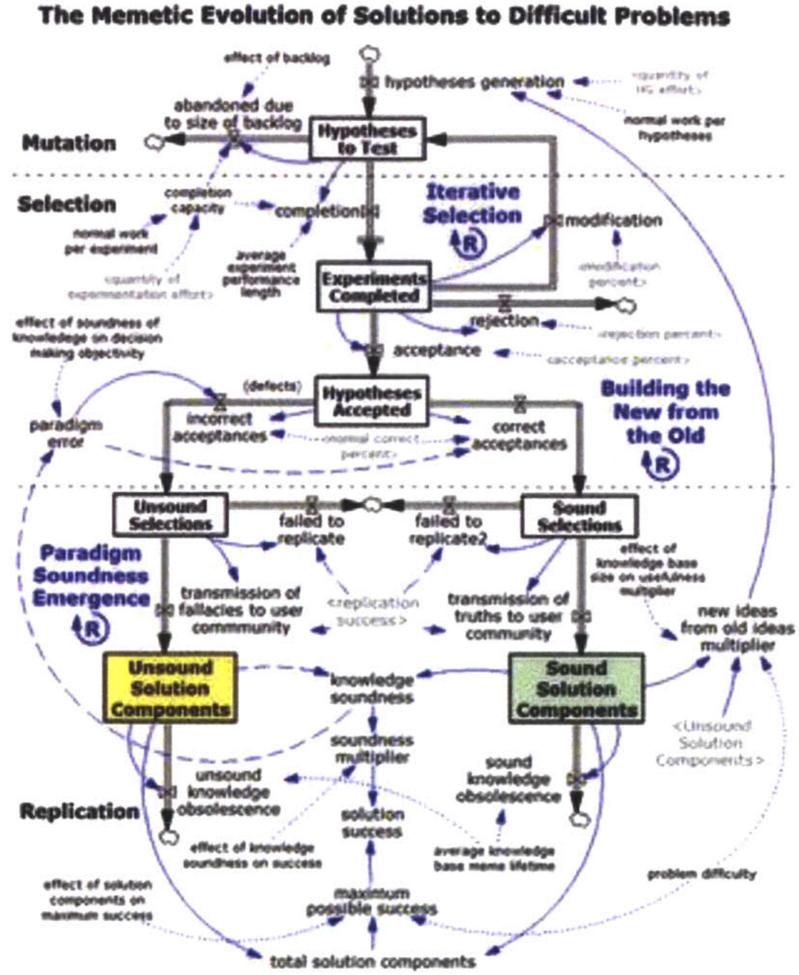


Figure 4.8: System Dynamics Model of Meme Solving Hard Problems (NOQ, 2010)

The concept of the meme is an important one, as it codifies information elements that can be selected, reused, replicated in human minds. We would like to propose a meme analogue for system architecture. We can call them "semes" (pronounced "seams", and appropriate representation as it the functionality of systems, including world-sized socio-technical systems, is often determined by effective interfaces or seams!). Semes are a special subset of memes that can then form combinations of fundamental processes that deliver a larger functionality in a system architecture. Semes are contained within architectures and all architectures are created by multiple semes. Semes themselves are thus replicated based on the success of the architecture in its environment and the applicability of that seme in the adapted or evolved architecture.

Semes have defining attributes that go beyond structure of the fundamental processes that create them. They also have state limits and definable factors. All of these variations in semes and then variations in architectures can be evaluated. The seme concept describes the underlying reason for "dominant designs" as we have seen in technology strategy.

When required to build a sustainable architecture and a large socio-technical system and deploy it, the Leader-Architect develop them from proven sets of fundamental processes and then ensure these sets would not only be fit for the current operating landscape but the future operating landscape that the system will have a hand in creating. Architecting for co-evolution by thinking ahead to how the system will change the very environment it was designed for.

If we are to do this, it is vital that the propagation of semes (ideas, memes etc.) needs to happen without much variation. There is a well known equation in information and probability theory shown below in Equation 9.

$$Informatin = \log_{10} \frac{1}{P_{event}} \qquad (9)$$

Thus the more improbable and observed event is the more information is contained with in it. So given that memes, ideas and semes themselves are all information, a larger probability distribution has lower information content in bulk. And as the idea of any system architect is to lower the system entropy and the entropy is measure of information content, variation in the original information packet will result in lesser impacts to system entropy. Ultimately the more nuanced way to say this is, if semes are to propagate and get selected effectively, then we must maintain the variation of the seme itself until it is time to have purposeful variation when needed. This will be explained in greater detail in a later section.

CONDITION 10: Visualization of information, interdependencies, status, monitoring

In order for Condition #9 to hold true the visualization of information is incredibly important. From P&IDs, to dashboards, to network diagrams to design structure matrices, the options for data visualization are many. However, for the most complex socio-technical systems, visualization of complex multidimensional information is tantamount to success in the most challenging human endeavors. This includes in the monitoring and observation, in the coordination of action phase and the in the resultant feedback loop of reaction assessment. This includes being able to visualize interdependencies at all levels, between people, technical systems, sub-systems, etc. This ability to visualize can even extend to principles and architectural evaluations. As semes were discussed above, the combinations of many semes and a deep understanding of the interfaces will also necessitate the ability to visualize semetic systems and compare them. What follows is an example of one such way of actually visualizing system architecture performance and comparing approaches. It is not intended to be an exhaustive example of data visualization, but serves to demonstrate the need for creative ways to visualize complex information and analyze it quickly to reach conclusions.

There are many salient ways to assess and visualize the goodness of a particular system architecture. The conventional ways are multiple variants of the following, all dressed in a multitude of ways. First one defines the initial value attributes and functional goals of the system, either the primary functions and the "ilities" (or both), defining these with some level of precision, so that it can be argued they are the same standard of measure to a varying population of assessors and devoid of as much subjectivity a possible. Then with these yardsticks in hand for system attributes, one places a myriad of potential architectural concepts (functional mappings onto form) up for scrutiny against these listed, objective needs and wants. Schema are introduced for weighting the importance of each criteria of selection if needed (some schemes actually warn against using a weighting system) enabling each potential system architecture to receive a score. The better the score, the better a given system architecture being assessed relative to its rival architectures also being assessed. This is the absolute assessment approach. Alternately the assessor can compare the architecture's performance against the selection criteria by comparing it to a designated standard or datum. This is the relative assessment approach.

This tried and true process is at the heart of almost all matrixed-based selection tools, such as utility function charts, Pugh concept selection diagrams. What we propose to do is go away from this somewhat workmanlike system to what we purport to be a truly innovative way of visualizing and assessing different architectures. It should be known a priori that not ALL the elements and information required to make this assessment scheme a bona fide and robust process is yet established or exists (the true indication of an innovative approach). So we ask that the reader imagine the existence of some of the required datasets for the process, even though they do not yet exist. The need for this suspension of rigor will become apparent in the following paragraphs.

Our system is based on the fundamental assumption (Crawley, 2010),

"There exists a universal set of fundamental prescriptive principles of system architecture, that when followed, maximize the functional effectiveness and value of a system."

And this statement is axiomatic. It is merely the job of the Leader-Architect (and in this case the assessor) to find these universal principles. Our first step was to start with a representative set of these principles and begin to categorize them. It should be noted that this set is merely a starting point and example and the reader should not focus heavily on validating or invalidating the principle, but in understanding that they are a viable starting point for demonstrating our critical evaluation scheme. We list 11 such principles, which yielded the following high level categories:

3 Principles related to Form and Function
3 Principles related to Value Definition
5 Principles related to the Architecting Process

These are shown in the mindmap below:

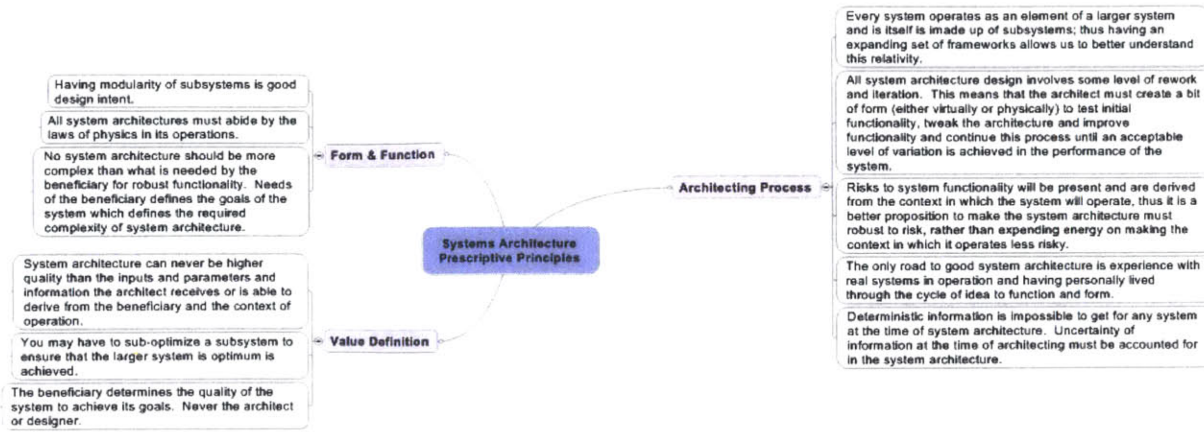


Figure 4.9: Mindmap and thematic aggregation of 11 system architecture principles.

By documenting these principles, one can begin to semi-objectively determine the **adherence** of any given system architecture or competence of given architect as embodied in the architecture itself. The scale that is utilized is an adaptation from Bloom's Taxonomy of Learning (Anderson, 2001). We have constructed a simple five point scale that traverses the gamut of awareness of the principle to radical innovation around the use of the principle itself in bold and exciting new ways – that is frontier expansion.

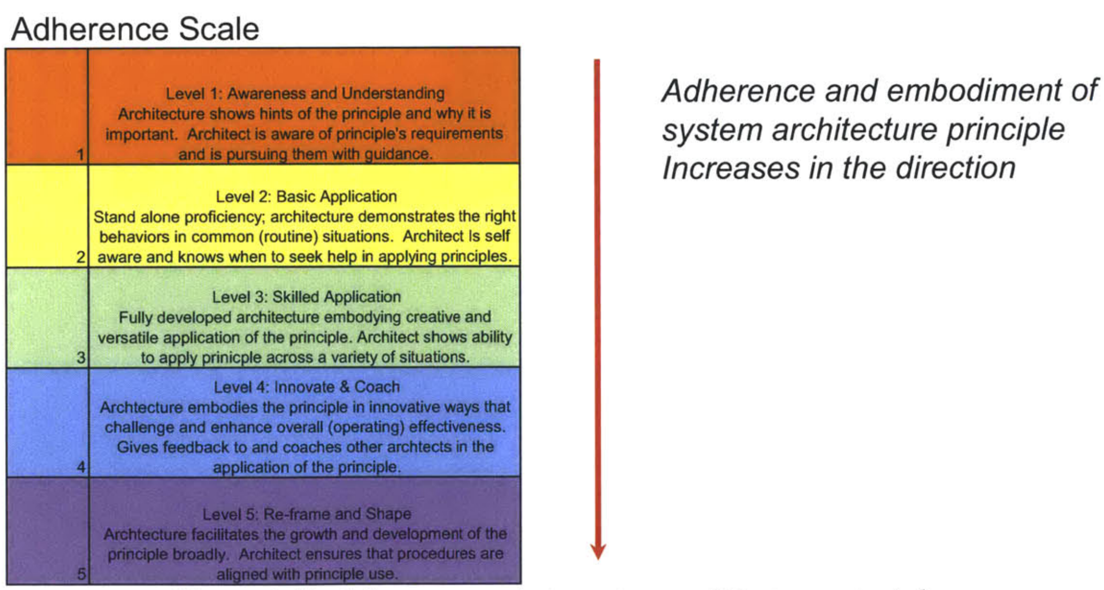


Figure 4.10: Adherence scale to system architecture principles.

The final element of innovation to our critical architecture assessment process is the actual visual representation of the assessment in ways that can allow for the visual comparisons of various system architectures through the lens of adherence to principles. We have chosen to use the radar plot method. In the figure below, the blue and pink outlines are assessments of two fictitious system architectures weighed using the 11 principles and the 5-point adherence scale above.

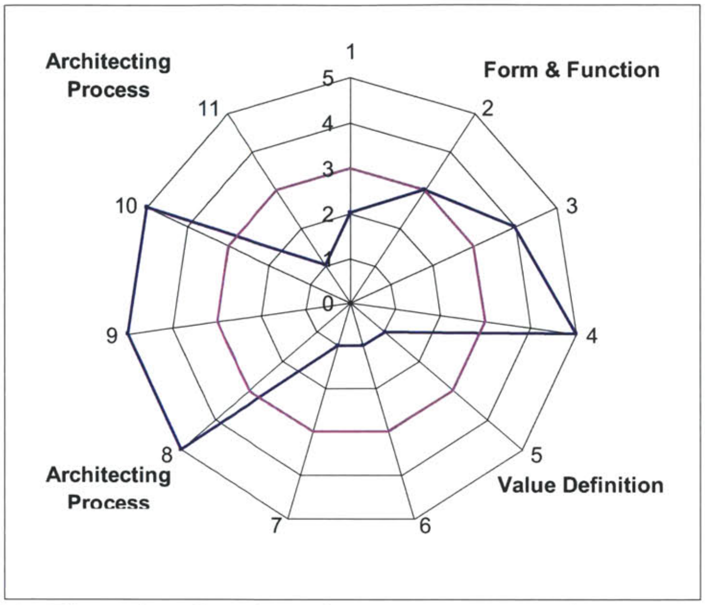


Figure 4.11: The radar plot of two fictitious system architectures (SAPARP).

We call this diagram a system architecture principles adherence radar plot or SAPARP. The underlying premise here is that we seek to MAXIMIZE the area that is bound by the colored perimeters. This is a general goals and one measure of goodness of the system architecture. The logic is as follows. Because we assume there are fundamental principles in systems architecture, we assume that adherence to such principles is a measure of goodness. If we can visually represent the adherence in a way that quantification is possible, then we have a means of measuring goodness.

Further and deeper analysis of this method uncovers an increasing amount of utility. While the maximization of bounded area is a directional goal, the actual bounded shape is of interest as well. It is interesting to not for instance that the physical area of the blue and pink lines above are actually near identical. The unshapely way in which the blue line achieves the bounded area X is in sharp contrast to the even and symmetrical way the pink link achieves the same bounded area X. So which is better?

To answer this question we can take one of two tacks.

Empirical Brute Force:

One says that it is not possible to answer which is better. Rather we can begin to keep records and create databases of various assessed system architectures overtime. As we look at this library or dataset (the one referred to above) we would then be able to do several things once the dataset has reached a critical mass. We could begin to use pattern recognition techniques to bucket different shapes and see how they correlate to real world system performance. How far did the system fall short if the functional and "ilities" goals it had and how is that related to assessment shape? Based on some correlations, we can hint at first principles causation. In much the same way as one could derive complex postulates from Euclid's initial axioms, we can built causal arguments from the set of principles and the extent of adherence and their relation to intended and emergent behaviors of the system. Lastly, based in this pattern recognition and classification, and causal models, we can also begin to make predictive calls based on some the assessment shapes above. "A fish shaped assessment leads to the following boons and busts in the resultant system, while a completely spherical one leads to the this other type of behavior." This empirical brute force method requires data mining and model formation and finally some predictive capability. It backs into what is "good". It takes quite a bit of time to answer the question.

A recommended approach is the following:

Axiomatic Approach:
We can invoke a simple axiom.

"Given roughly equal areas on a radar plot, the shape that has the minimal complexity (irregularity) is better."

Why do we say this? What this means is that we prefer situations where we have balanced adherence to ALL the principles, vs. situations where a smaller subset of principles are adhered to a greater extent and at the expense of others. A balanced allocation of adherence is preferred and thus indicates that a system architecture that adheres more in a balanced way to the principles is better than one that doesn't. While an effective heuristic, it introduces the problem of being able to quantify shape complexity or irregularity if one is to have a true comparison of architectures that exhibit roughly the same surface area as the other. Luckily there is a method described in computer science that has a reasonable algorithm to do this. Su et al describe a complexity (or irregularity) measure of 2D shapes. Three attributes are first calculated to separately describe the complexity of the boundary, the global structure, and the symmetry of the shape. Then, a model consisting of the above parameters are developed to describe the entire complexity of the shape. This model further incorporates the scale information into the boundary complexity definition and also into the determination of weights associated with different properties. Su et. al. have gone as far as to test the complexity model on a synthetic dataset, and demonstrate its application on screening shapes extracted from noisy shoeprint images.

The application to our problem is the ability to objectively choose between two or more architecture radar plot assessments (and with scale factors if needed) and say which ones are more regular and thus better.

The authors feel that these initial notions provide an interesting intersection of image analysis and pattern recognition with a systematic study of system architectures. To further innovate on the idea, one can imagine adding a time dimension to the static radar picture, mapping a system architecture throughout its life cycle that is system conception through actual system utilization. Adding this time dimension may even potentially introduce the ability to compare 3D shapes for common metamorphoses throughout a life cycle.

This visualization of architecture was given as one example of creative ways in which data visualization can be simplified. All in all, the condition of having information of complexity available and searchable simply is at the center of this condition.

CONDITION 11: Segregation of decisions and actions by time cycles

This last condition is perhaps the most new and fundamental observation coming out of the meta-study on the management science and change models. This is the ability to segregate people and assets in the decision making time cycles that vary between great times cycles (years and decades) to tiny moments (seconds to hours). We posit a bold axiom that the most impactful and effective way to organize a design or propagation effort is by segregating these time cycles.

We will explore this model in depth and it will be called the "Time Shell Model". Decision-optimized, time cycle segregation directed at massive organizational structural change was first constructed by Dr. Robert Cournoyer of Display Products at Eastman Kodak, when he developed a method for radically jump-starting a lean operating model in development and manufacturing in 2002.

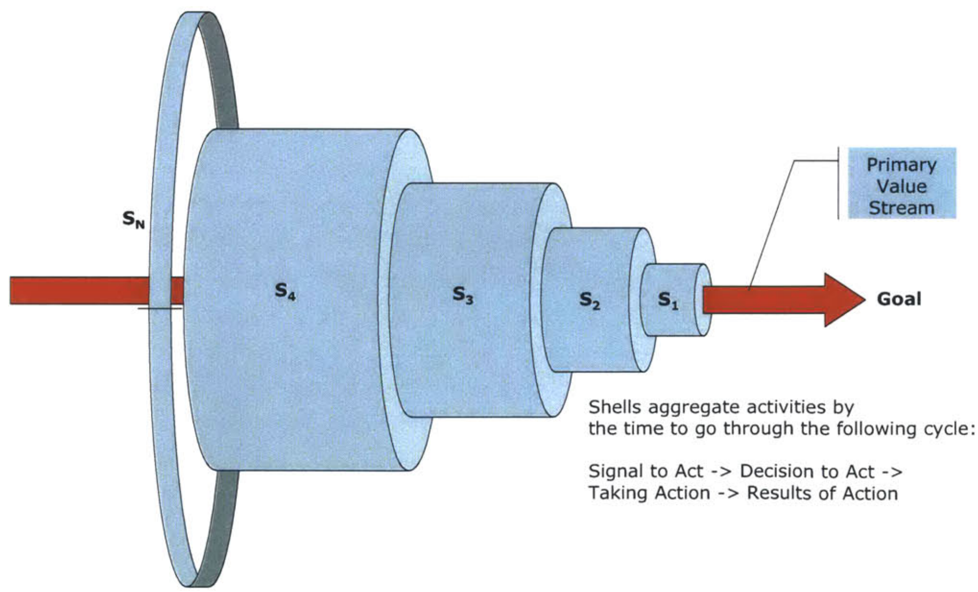


Figure 4.12: Time Shell Model depiction showing the segregation of time cycles.

Figure 4.12 shows a visual representation of this Time Shell Model. The method essentially segregates and empowers human and technical assets by the examining the time frames from "signal to action to response to result" chain using a specific value stream as the central grounding point. The value stream at the center (say Shell 1) touches the central value stream that is the most important to the construct. For example, if it is, say, the construction of a bridge, Shell 1 would be that which contains people and assets central to the actual laying of brick, or mixing of the cement etc. These signal-to-result time cycles, in this example are likely in the order of hours to a day. The shell beyond this, Shell 2, could well be the weekly planning cycle that determines the entry of materials to the area which could well be in the weeks to months time cycle. Shell 3 could then be the city planning activity which actually determines the needs for a bridge and the routing of traffic etc. The concept of the Time Shell Model is that optimality of execution is achieved when the resources dedicated to each time cycle is segregated as much as possible with purposeful connections built between shells, which we will call the "cross-shell pools".

The fundamental axiom of this is all decision making activities in other in other shells should map to how they will impact the central value stream around which Shell 1 sits and make Shell 1 performance as optimal as it can be. This is not a precise methodology and thus requires a bit of judgment and imperfection but this is how it would work if moving from a non-time cycle segregated situation to a time cycle segregated situation.. The first step is to ask what the final product of some value stream is. What is the reason for being of the effort? That is the central value stream or product or deliverable? We would first identify the critical value streams or products (meta-products) e.g. project plans, packaged goods, analyses, verbal advice, and patient visit, whatever it might be. The second step would be to use the central value stream to set the time basis for the decisions and determine how this central value stream is organized. One can then begin to move from the value stream out in time scales of decisions (starting with the simplest segregation of time, e.g. hours, days, weeks, months, quarters, years) and right decision types that impact Shell 1 in those time scales. For example, a viable Shell 1 question can be "what is this defect and how can I rectify it"? An adequate Shell 2 question can be "what are patterns in defects we see and how do we rectify them?". An adequate Shell 3 question might be "what are the new products or capabilities that Shell 1 has to incorporate?" and an adequate Shell 4 question maybe the "what new value streams must be constructed?". As one can see, the time cycle from signal to act to results of action vary as one moves from shell to shell, and increase as we go to higher shells. The next step in the time shell model is to start from the people who are making those decisions today, and their logical groupings. Do they bundle naturally into hard line or dotted line structures? If not, what are options with moving people and structures around to more naturally bundle into time scales? Lastly, one can think of the changes and then the cross-shell structures (we call them "pools") that will be needed to assure the right communication and escalation This allows for doing an organizational Design Structure Matrix (DSM) analysis based on time frame of decisions and this should partition according to like time frames (shells). Once the Shell segregation future is determined, the restructuring can then happen.

This segregation from high time cycle and low time cycle shells is found again and again in the meta-study of management sciences above. While not explicitly said, it is our assertion that this segregation is likely the reason why the tier management and hoshin kanri processes found in lean enterprises actually work. In lean enterprises, the large time cycle decisions on the order of years to decades are made by the senior most management in running regular operations and by the chief engineers (shusa) whereas the day to day hour to hour decisions are enabled through wonderful visual controls like andons etc. (Womack, 2007).

But why should it work in the first place? In order to show that the natural or purposeful time cycle segregation is preferred to random transmission between shells we created a simple system dynamics model that describes some observed events within organizations. This is shown in Figure 4.13. In this model, we have kept it generic between all three of the organizational types described by Christensen (Christensen, 2007): Value-Adding Process Businesses, Facilitated Network Businesses, and Solution Shops. For example, in a value-added process business, Shell 1 is clearly the physical object to which value is being added, in a facilitated network business, Shell 1 is wrapped around the activities of transactional routing, and lastly in a solution shop (which many design efforts can be), Shell 1 can be the actual evaluation of parts of the problem and creating parts of the solution.

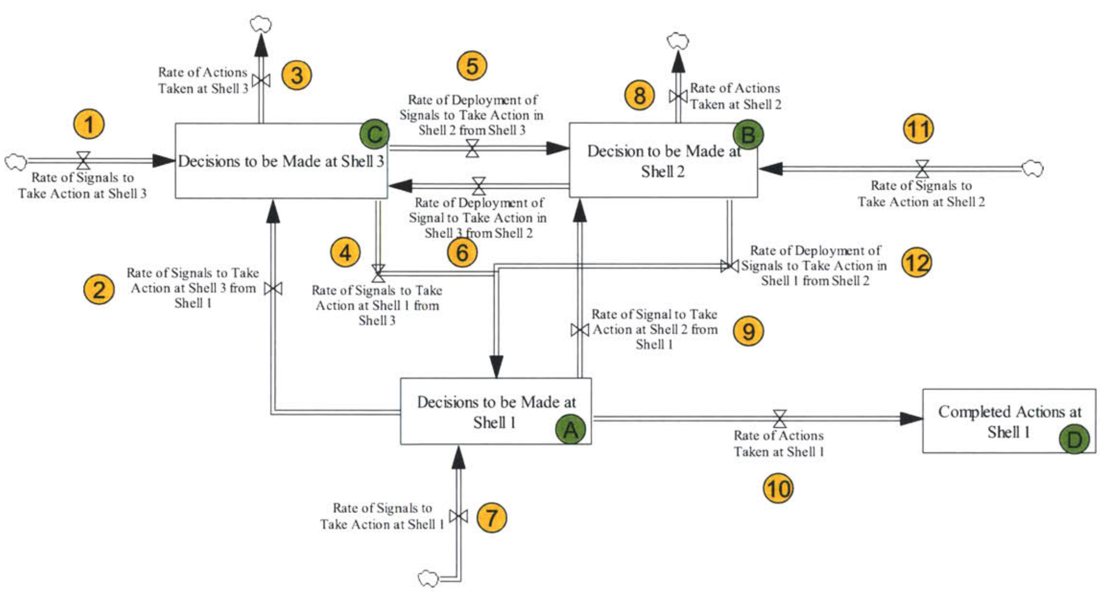


Figure 4.13: Simple model for 3 shells at different time scales.

For purposes of this model we define the item flowing through as signals-resolution pairs. The standard time unit was set as days and the shell closest to the primary value stream is Shell 1 (S1). Here the rate of signal to result is on the order of day. Shell 2 (S2) is on the order of months and Shell 3 (S2) is longer on the order of a year. Here are some representative definitions:

Flow #1 = the rate of entry of exogenous signals to act coming into S3
Flow #3 = the rate of resolved signals, not needing to be acted on by other shells.
Flow #2 = the rate at which S1 (a lower shell) deploys signals back up to S3 (a higher shell)

Stock D = completed actions at from Shell 1, the true delivery of value

For simplicity, we have not shown the flow interconnections and their dependencies on stock levels. For example, in the model, and Flow #5 depends on the Stock C level.

A random and non-segregated model is where we have equality of flows out of the stocks. A time cycle segregated network would be one where purposeful imbalances would be set up for shells so that say Flow #1 (S3 to S1), vs. Flow #3 which represents signals taken care of without impinging on other stocks (or Shells).

This simple model shows that the decision cycle time segregation is indeed empirically the better option. The Time Shell Model is also tested empirically in the empirical testing section.

SECTION 5: THE NECESSITY OF ALL CONDITIONS

A semi-quantitative way of determining challenge level in human endeavors and 11 hypothesized conditions for success in these challenging endeavors have been developed in the previous sections. It is in this section that we will utilize the 20 greatest engineering achievements of the 20th century as defined by the National Academy of Engineering (NAE) to test the following central hypothesis and premise in this paper:

> *The greater the challenge level of a successful human endeavor, the more of the necessary conditions were present.*

This is one step along the way to back into the corollary:

> *All 11 conditions are necessary for success in the most challenging human endeavors (band 5-6 and band 6 and above as seen in the challenge level definition of Section 2).*

It is difficult to do this analysis by utilizing the full arch of each engineering achievement highlighted in Table 2.1. Rather than attempting that, we have selected specific points in the timeline and events in the socio-technical achievement that serve well to prove the point and provide some distribution of challenge levels, even in the top 20 engineering achievements. It is fairly obvious (yet incredibly important) to note that for this go-around we are only looking at **successful** endeavors. In other words, we are at first testing for necessity, not optimality. In the section after this, we will use specific case studies within a company to test optimality going into a detailed discussion of first hand accounts of contemporary initiatives in large multi-national firm in Section 6. For this section we focus on the following events in the 20th century timelines of the greatest engineering achievements as the specificity of these events and changes allows us to characterize the challenge level and the appropriate mitigation:

1. Electrification – Looking at the rural electrification program as a part of the New Deal that gave power to thousands of people in the middle parts of the US. (circa 1935-1941)

Figure 5.1: Rural electrification plan as a part of New Deal, 1938.

2. Automobiles – The introduction of the moving assembly line allowing for affordable and accessible offering of cars to millions of people. (circa 1913-1927)

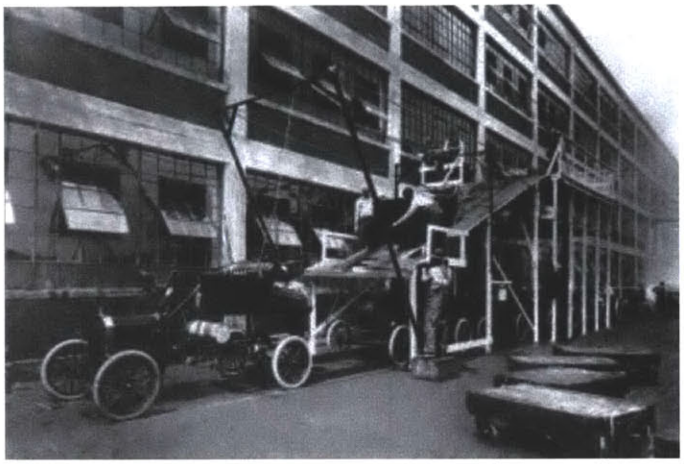


Figure 5.2: Experimental assembly lines at Ford Motor Company, 1913.

3. Airplanes – Advances in aeronautical research, specially in controls and propulsion as a part of the National Advisory Committee for Aeronautics in the US derived from needs of higher altitude, higher speed, and greater maneuverability due to WWI. (circa 1915-1927)

Figure 5.3: Logo of National Advisory Committee for Aeronautics, 1920

4. Water Supply & Distribution – The water distribution effort that led to increasing clean water supply to Los Angeles, CA. (circa 1902 – 1913)

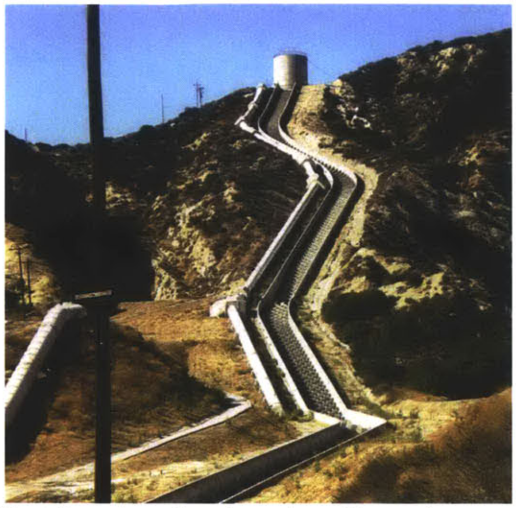


Figure 5.4: First Los Angeles Aqueduct Cascades, completed 1913.

5. Electronics – Migration away from germanium based to silicon-based transistor, through mass production of integrated circuits using deposition and etching. (circa 1954 – 1965)

Figure 5.5: Original integrated circuit from Jack Kilby, 1958.

6. Radio & Television - The vision of radio broadcasts, the refinement of transmitters, tuners, amplifiers and components to the production of 1.5 million radios a year by Radio Corporation of America (RCA). (circa 1915 – 1923)

Development of the television and commercialization to mass audiences through the RCA standard. (circa 1927 – 1942)

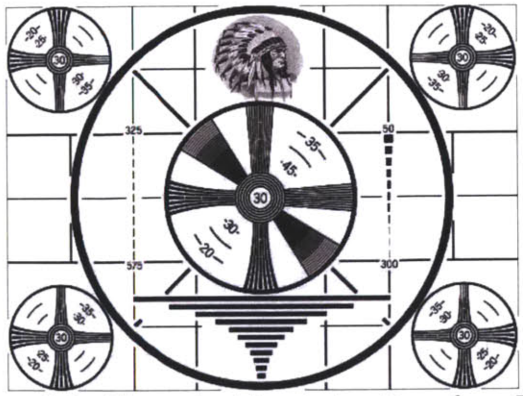


Figure 5.6: First television test pattern from RCA.

7. Agricultural Mechanization – Conversion of steam traction engines to internal combustion engine tractors and mass production of Fordson tractor to take 75% of US and 50% of global market. (circa 1902 – 1920)

Figure 5.7: Fordson tractor from European museum

8. Computers – Completion of the SAGE project for air defense controls through processing of ship, plane, and other radar and combining with weather and other data by IBM and MIT Lincoln Laboratory eventually leading to the creation of System/360 through IBM. (circa 1950 – 1965)

Figure 5.8: SAGE project IBM and MIT, 1954.

9. Telephone – First transatlantic telephone cable going from North America to United Kingdom called TAT-1, an international collaboration. (circa 1956 – 1959)

10. Air Conditioning & Refrigeration – The invention and implementation of dew point control allowing for humidity and temperature control and balance for complicated industrial and manufacturing processes. (circa 1902 – 1909)

11. Highways – The formation of the National System of Interstate and Defense Highways which led to the development of the network of expressways that traversed the country with now half a trillion miles being traversed every year on interstates. (circa 1954 – 1990)

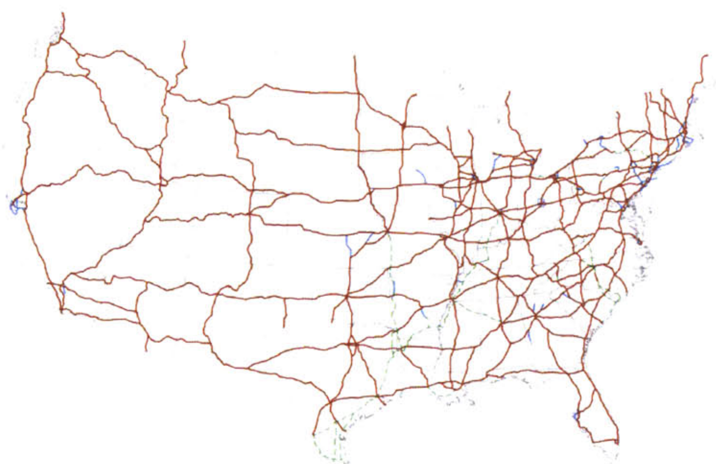


Figure 5.9: Interstate system in the United States after Eisenhower administration initiated Highways Act.

12. Spacecraft – The initiation and successful completion of the three NASA programs of Mercury, Gemini and Apollo landing humans on the moon. (circa 1960 – 1972)

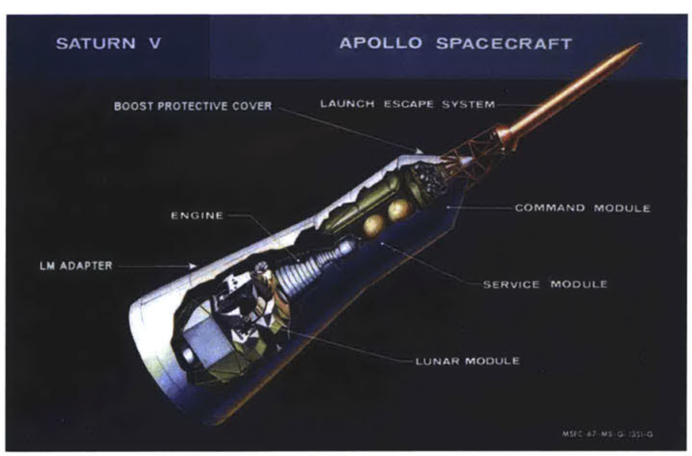


Figure 5.10: Full Apollo Spacecraft, NASA, 1970

13. Internet – The creation and demonstration of ARPANET a distributed network intended to share information resources and communicate even if large parts of the network are destroyed. (circa 1966 – 1973)

14. Imaging – The design and release of the first mass produced consumer camera (the Kodak Brownie) along with the associated supply chain from pressing the button to delivered pictures making photography affordable for all. (circa 1898 – 1942)

Figure 5.11: Kodak Brownie No 2. Eastman Museum

15. Household Appliances – The propagation of household equipment that took advantage of rural electrification, small motors and resistive heating elements. (circa 1901 – 1919)

Figure 5.12: A set of familiar appliances

16. Health Technologies – The development of human vaccines for items such as measles, mumps rubella etc. (circa 1955 - 1965)

The completion of the Human Genome Project leading to molecular medicine for items such as dosing of blood coagulation, breast cancer identification and treatment. (circa 1991 – 2009)

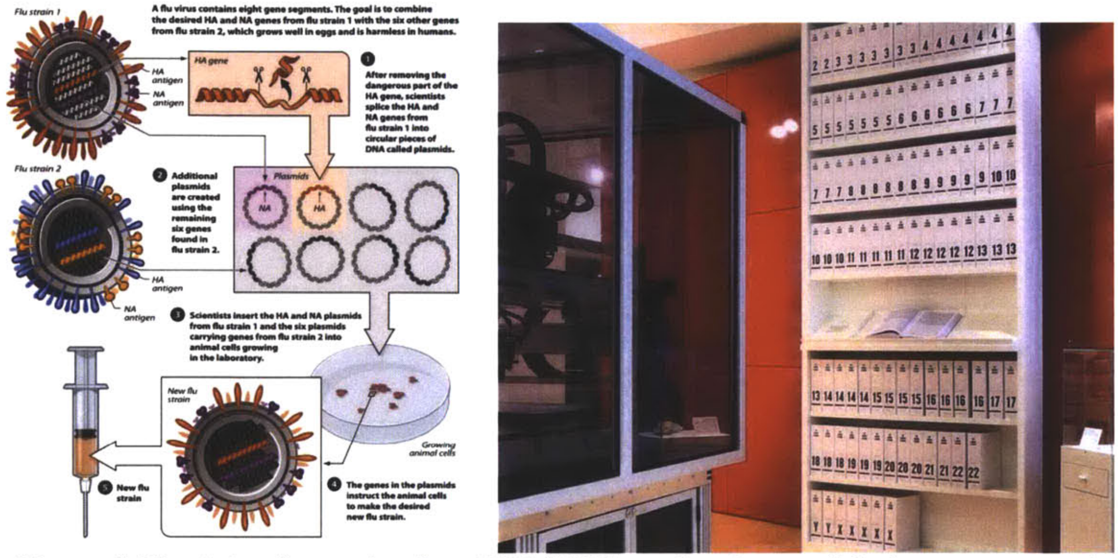


Figure 5.13: Avian flu vaccine from NIH (2010), and a picture of the human genome in the form of books .

17. Petroleum & Petrochemical Technologies – The development of high-pressure hydrogenation to new refinement processes to the creation of synthetic oils. (circa 1913 – 1920)

18. Laser & Fiber Optics – The development of low-loss glass that met theoretical purity standards to the linking of major cities with fiber optic communication. (circa 1972 – 1980)

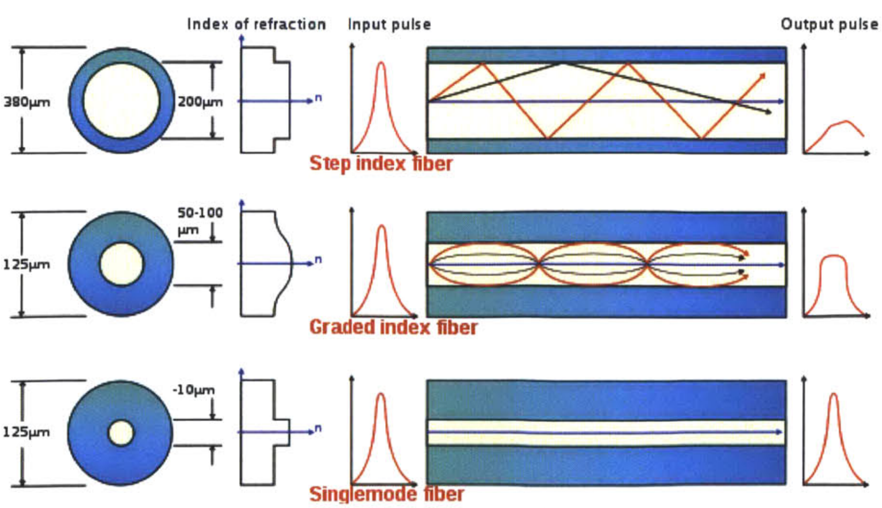


Figure 5.14: Optical Fiber Types

19. Nuclear Technologies – The start and completion of the Manhattan Project yielding Uranium-235 at a purity level that allows for the creation of the first atomic bomb, but also yields science that creates chain reaction fission technology capable of sustaining energy creation. (circa 1939 – 1945)

20. High-performance Materials – The development of nanomaterials and the first wide-spread utilization of nano-materials for lubrication, composite coatings, and materials. (circa 1990 – 2002).

The analysis of each of these specific events in the broader timelines of the NAE engineering initiatives allows us to do that assessment contained in Table 5.1.

Socio-Technical Event	Challenge Level	Conditions	Govt
19. Nuclear Technologies	6.181000961	11	Y
16. Health Technologies	5.975148907	10	Y
1. Electrification	5.943412233	9	Y
12. Spacecraft	5.929211812	11	Y
3. Airplanes	5.743223446	9	Y
4. Water Supply & Distribution	5.644533235	11	Y
14. Imaging	5.587216278	10	N
11. Highways	5.341425147	8	Y
8. Computers	5.332376882	10	Y
13. Internet	5.192389568	11	Y
2. Automobiles	4.564534232	11	N
7. Agricultural Mechanization	4.532212214	7	N
9. Telephone	4.036618865	7	N
5. Electronics	3.454435663	8	N
10. Air Conditioning & Refrigeration	3.441452093	9	N
6. Radio & Television	3.421542323	9	N
20. High-performance Materials	3.181940897	4	N
17. Petroleum & Petrochemical Technologies	2.908153613	5	Y
18. Laser & Fiber Optics	2.589699882	9	N
15. Household Appliances	2.188689124	4	N

Table 5.1: Challenge Level of Successful Socio-Technical Events and Number of Conditions Present.

This allows then to do a linear regression analysis of these numbers shown in Figure 5.15. This analysis yields an R-squared value of 0.5054, a reasonable correlation for a dataset of this level of interpretation, variation and data specificity. This R-squared gives reasonable validation for the initial statement we made that the greater the challenge level of a successful human endeavor, the more of the necessary conditions were present. Also this analysis gives us reasonable confidence that most (if not all) of the 11 conditions are necessary for success in the most challenging human endeavors (band 5-6 and band 6 and above as seen in the challenge level definition of Section 2).

To take this analysis one step further, it is informative to examine some emergent patterns from the most challenging of these successful endeavors.

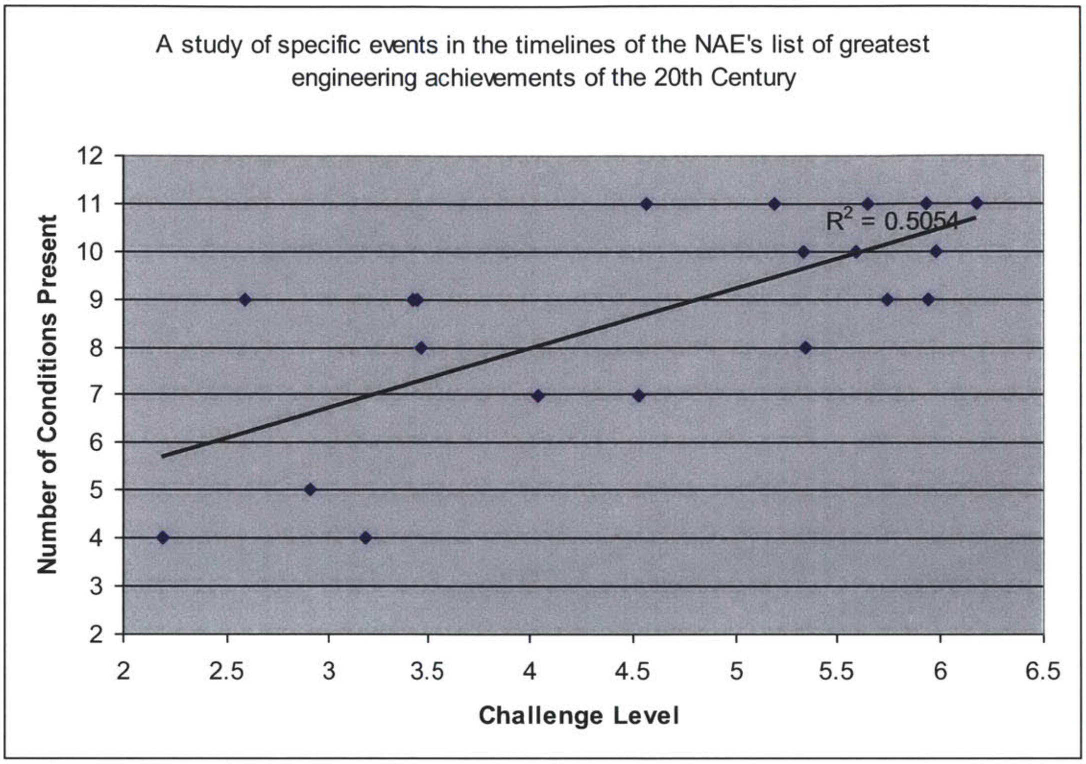


Figure 5.15: A correlation of the number of conditions present vs. the challenge level of successful engineering initiatives.

<u>Observation 1</u>: 9 out of the 10 successful endeavors above challenge level of 5 have some government involvement to structure, set time tables, fund, resource or legitimize the effort. Table 5.2 shows the events ordered in descending order of challenge. Projects such as rural electrification, the space program and highways systems in the US were driven by a combination of executive action (FDR, JFK and Eisenhower in these examples) with some government legislation to act. As the challenge level drops below the 5-6 band, the efforts are more "emergent" and less directed from some overarching government or public sector act. Conversely, 9 out of the 10 successful endeavors below the challenge level of 5 have very little or no governmental involvement to structure, set time tables, fund, resource of legitimize the effort and was largely done through the non-for-profit academic efforts and the private sector partnerships. While this required partnerships and aggregation, they were much more driven by market forces of consumer demand discovery and fulfilling them in innovative and large ways.

Socio-Technical Event	Public Sector Driver
19. Nuclear Technologies	The Manhattan Project
16. Health Technologies	Dept of Energy, National Institute of Health
1. Electrification	FDR and Rural Electrification Administration
12. Spacecraft	JFK and NASA
3. Airplanes	National Advisory Committee for Aeronautics
4. Water Supply & Distribution	Los Angeles Water Department
14. Imaging	N/A
11. Highways	Eisenhower & National System of Interstate and Defense Highways
8. Computers	Semi-Automatic Ground Equipment (SAGE)
13. Internet	ARPANet Project, Advanced Research
2. Automobiles	N/A
7. Agricultural Mechanization	N/A
9. Telephone	N/A
5. Electronics	N/A
10. Air Conditioning & Refrigeration	N/A
6. Radio & Television	N/A
20. High-performance Materials	N/A
17. Petroleum & Petrochemical Technologies	N/A
18. Laser & Fiber Optics	N/A
15. Household Appliances	N/A

Table 5.2: Public Sector Drivers for Most Challenging Successful Engineering Achievements

Observation 2: The higher the challenge level, the more work was borne of some burning platform boiled down to a matter of live or death or impingement on national security. It can be argued that many of the most challenging endeavors were generated in response to the public sector actions needed to defend the nation against during the two World Wars or the large and expansive Cold War. These burning platforms eventually were joined with compelling destinations, for example the idea of space discovery as the goal of winning the space race and travel and commerce for the highways program. However initially these programs started with the fear and impetus to protect the people. These drivers are different from the usual dynamic of market force driven innovations which usually start with a compelling destination first. Table 5.3 shows these and the preponderance of this dynamic at the higher challenge levels can be clearly seen.

Socio-Technical Event	Burning Platform Leading to Compelling Destination
19. Nuclear Technologies	World War II and Beating Nazi Germany to the Bomb
16. Health Technologies	Genetic/Preventable Disease Eradication, Healthcare Costs
1. Electrification	Great Depression
12. Spacecraft	Cold War - Soviet Union & Space Race
3. Airplanes	World War I
4. Water Supply & Distribution	Lack of available water in the fastest growing part of country
14. Imaging	N/A
11. Highways	World War II and need to have integral roads during attack
8. Computers	Cold War - Soviet Union and Bomber Intercept
13. Internet	Developing a bomb proof way of sharing information
2. Automobiles	N/A
7. Agricultural Mechanization	N/A
9. Telephone	N/A
5. Electronics	N/A
10. Air Conditioning & Refrigeration	N/A
6. Radio & Television	N/A
20. High-performance Materials	N/A
17. Petroleum & Petrochemical Technologies	World War II and Demands for Rubber & Synthetic Oils
18. Laser & Fiber Optics	N/A
15. Household Appliances	N/A

Table 5.3: Preponderance of burning platforms in the most challenging and successful endeavors

Observation 3: The higher up we go on the list the more prevalent the existence of Leader-Architects becomes. The Manhattan Project had Oppenheimer, the water distribution system in Los Angeles had the remarkable story of Mulholland at the center, and imaging had Eastman. Vaccines had the vision and tenacity of Hilleman while rural electrification required the conception of Cooke and the Internet and Arpanet fell to Roberts from MIT's Lincoln Laboratory.

Socio-Technical Event	Leader-Architect
19. Nuclear Technologies	Robert Oppenheimer
16. Health Technologies	Maurice Hilleman/Craig Venter
1. Electrification	Morris Llewellyn Cooke
12. Spacecraft	Wernher van Braun
3. Airplanes	Charles Walcott
4. Water Supply & Distribution	William Mulholland
14. Imaging	George Eastman
11. Highways	Frank Turner
8. Computers	George Valley/Jay Forrester
13. Internet	Larry Roberts
2. Automobiles	Henry Ford
7. Agricultural Mechanization	N/A
9. Telephone	N/A
5. Electronics	N/A
10. Air Conditioning & Refrigeration	Willis Haviland Carrier
6. Radio & Television	David Sarnoff
20. High-performance Materials	N/A
17. Petroleum & Petrochemical Technologies	N/A
18. Laser & Fiber Optics	N/A
15. Household Appliances	N/A

Table 5.4: Leader-Architects associated with the top 20 NAE engineering achievements list.

It is perhaps this trifecta of burning platform, public sector participation, and leader-architect that produces and interesting operational model that combines the 11 conditions in a tight knit and operational way. This will be our premise moving forward and is the reason for the sub-text of the title of this thesis. The Manhattan Project ranked the highest on challenge level and brings these elements tightly into focus and contained all of the 11 conditions at a high level. Modern day Manhattan Projects could embody the components of the 11 conditions in workable construct and an appropriate operational model for the combining public, private and not-for-profit sectors in ways that large human endeavors can be accomplished. This operational construct will be explored in Section 8, but it is worth describing a couple of aspects of the Manhattan Project as a case study of a successful one.

Author Richard Rhodes has spent an exhaustive amount of time learning about the making of the atomic bomb, living in the atomic age and the sunset of the Cold War atomic era (Rhodes, 1986, 2010). Cynthia Kelly has also presented detailed written accounts of individuals who lived through the Manhattan Project (Kelly, 2007). The details of these works and associated references provide a reasonable look into the construction of the Manhattan Project and its relation to the 11 conditions.

Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

-2-

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.

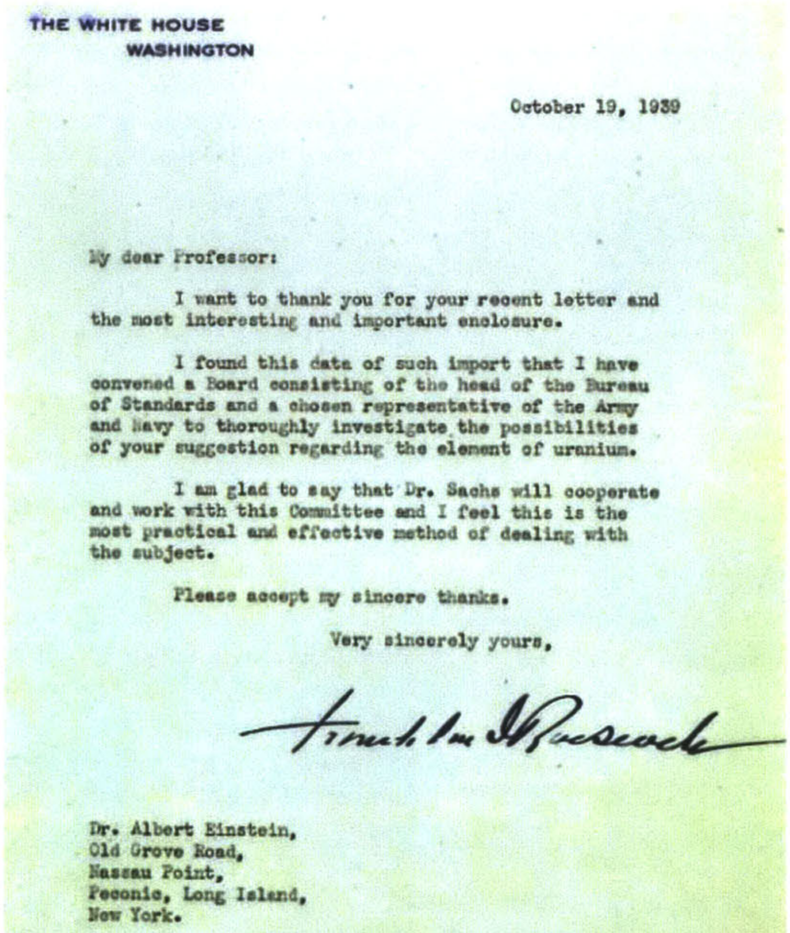
In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an inofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

b) to speed up the experimental work,which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,
A. Einstein
(Albert Einstein)


THE WHITE HOUSE
WASHINGTON

October 19, 1939

My dear Professor:

I want to thank you for your recent letter and the most interesting and important enclosure.

I found this data of such import that I have convened a Board consisting of the head of the Bureau of Standards and a chosen representative of the Army and Navy to thoroughly investigate the possibilities of your suggestion regarding the element of uranium.

I am glad to say that Dr. Sachs will cooperate and work with this Committee and I feel this is the most practical and effective method of dealing with the subject.

Please accept my sincere thanks.

Very sincerely yours,

Dr. Albert Einstein,
Old Grove Road,
Nassau Point,
Peconic, Long Island,
New York.

Figure 5.16: Correspondence between Einstein and Roosevelt providing the framework and impetus for the Manhattan Project

The burning platform (the first part of Condition #1) for the Manhattan Project and its initial impetus came from a famous set of correspondence between Albert Einstein and President Roosevelt (shown in Figure 5.16). An extremely credible individual from the not-for-profit academic sector (actually the letter was drafted by physicists Leo Szilard and Eugene Wigner and signed by Einstein) brought attention to an emergent problem to the public sector after which a tripartite partnership and structure was established with public, private and academic sectors.

The selection of Robert Oppenheimer as the Leader-Architect for the project set up some unique conditions (Condition #2). He most importantly was able to provide the compelling destination for the people of the project, equating urgency and progress of the project with the toll of human lives. Each day gone by meant more human lives lost in the war, but success meant a death blow to all war (second part of Condition #1, the compelling destination). That was the philosophical underpinning of the project, the end to all wars through the possession of military might above all others so that retaliation would be unthinkable. (Kelly, 2007)

As is needed of the Leader-Architect, he had a deep practical knowledge of his area of expertise, but at the same time had a broad integrative mind that allowed for a wide-variety of interests and vision. He was able to think in systems and interconnections which would not only think of the whole systems concepts inside and out, but also create views and visuals that allowed for problem solving at the systems and sub-systems levels. Oppenheimer's ability to be a practicing individual of not only physics but also of integrative sciences and his growing concern for the plight of humanity and political issues made him a person who could balance the moral and technical aspects (Condition #3). His intense interests in the mysteries of the universe and metaphysical and religious studies gave him a broader sense of something, and an ability to work in both the worlds of deterministic progress and uncertainty and ambiguity that come with making hard decisions with deep moral and ethical implications. This complexity of technical execution colored by the pondering over of the fundamental principles of operation from a moral perspective was rare in a single individual, but is critical for a Leader-Architect to have. Oppenheimer was in many ways an archetype of this type of individual (Rhodes, 1986). The construction of the Manhattan Project was around the group world-level physicists called the "luminaries", a group coincidentally of size 9 to 11 people (including individuals like Victor Weisskopf and Robert Christy to legends like Enrico Fermi and Isidor Rabi) looking at the overarching systems concepts for the bomb and how those pieces needed to come together (Condition #4). While the secrecy of the project prevented the broader globe to be engaged, Oppenheimer and Groves needed to manage an effective relationship where science and the intricacies of science had to be translated to military audiences. This took the form of seasoned stakeholder and change management as time progressed (Condition #5).

The structure of the program shown in Figure 5.17 allowed for the time-based segregation of decisions and execution with Oppenheimer and Groves looking at the longer term goals of the program while local execution could happen all with the intent of approaching self-sustaining fission reactions (Condition #11). The structure at the longest time-cycles and the highest level of integration was called the "governing board" (perhaps at higher Shell levels as per the descriptions in Section 3). The structure allowed for many of the other structural and information flow conditions we have defined as well, including transmission of information without variation up and down, sideways and across geographical areas across thousands of technical and managerial staff. (Conditions #9). Two important ways of information and knowledge flow were the master models and physical prototypes (artifacts) of the bombs themselves as well the regular written and explicit journals within the community like the *Los Alamos Primer* made for global awareness of technical issues across the space. For example, the first edition of the *Los Alamos Primer* laid out the blueprint for the whole project in about 20 pages by Robert Serber. This level of conceptual alignment was critical and a perfect example of information flowing back and forth without variation so that evaluation can happen at the right places. There are accounts of the importance of this fundamental tenant of information and knowledge transfer protected at great lengths even when threatened. For example, information from the Tinian island tests were being intercepted by the military and being prevented from reaching scientists at Los Alamos, scientists involved went through exorbitant, self-sacrificing means to get the information unfettered to the right hands under Oppenheimer.

Early on in the project, Oppenheimer realized that having each one of the scientists commissioned and security within the scientific realms of the Manhattan Project would be at great detriment to establishing the right in-flow of brilliant and dedicated resources into the project. This was shown to be true when influential scientists from MIT had the de-militarization of information as a prerequisite of them joining the program. This assurance came with some seclusion principles but assured the right in-flow or people with the right skills levels and dedication. The establishing of the distributed geographical facilities and assets and associated non-personnel resources including funding completed the full Condition #7.

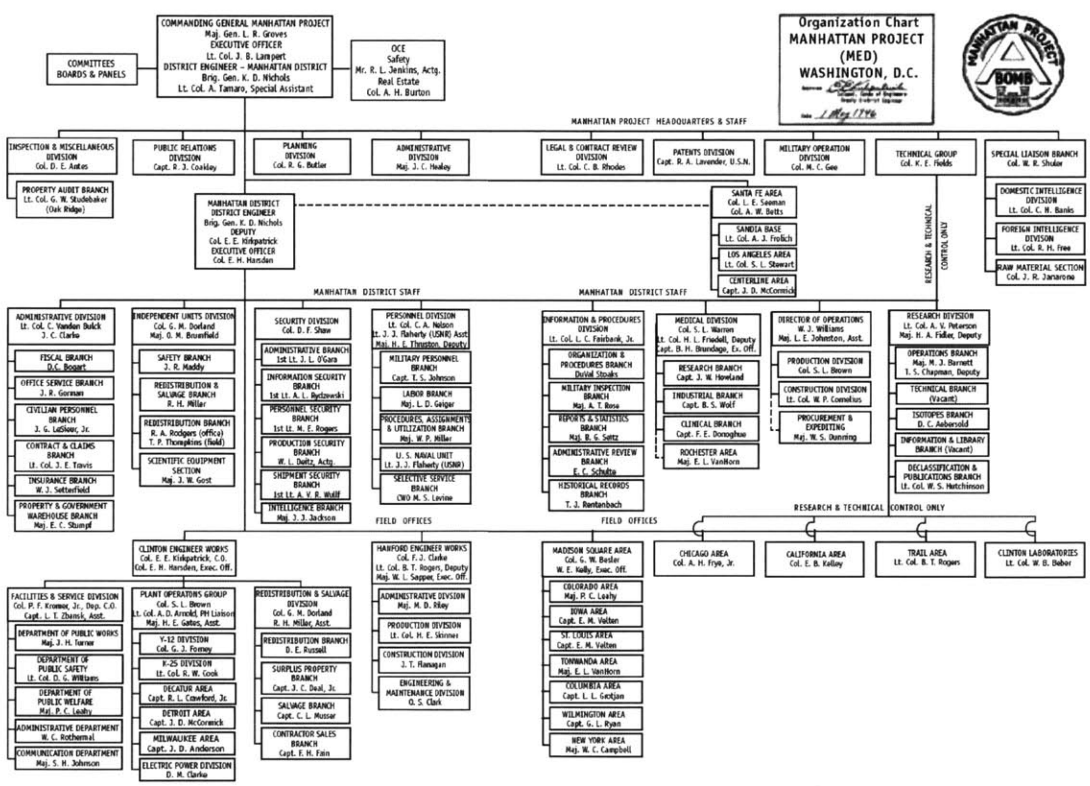


Figure 5.17: Organizational structure of the Manhattan Project allowing for time-based segregation

The program grew to being fluidly connected to private, public and not-for-profit sectors of the US, the network of research sites shown in Figure 5.18. This chart does not adequately depict the private sector partnerships (e.g. Stone & Webster and Tennessee Eastman, a then subsidiary of Eastman Kodak). The deployment of tasks down from the governing board to this broad network at the epicenter of which was Oppenheimer and Groves as well as well as the ability to getting bottoms up innovations from the floor up was critical and an in practice example of Condition #8. Through challenges in one endeavor or facility in the network, redeployment could happen while keeping to the True

North of weapons development and the intended capability to end the war (Condition #6). After the dropping of the first bomb on Hiroshima, the summary of the efforts was given by President Harry Truman in his public address of 6th August 1945, speaking of the 125,000 people enterprise of the Manhattan Project:

> *"But the greatest marvel is not the size of the enterprise, its secrecy, nor its cost, but the achievement of scientific brains in putting together infinitely complex pieces of knowledge held by many men in different fields of science into a workable plan. And hardly less marvelous has been the capacity of industry to design, and of labor to operate, the machines and methods to do things never done before so that the brain child of many minds came forth in physical shape and performance as it was supposed to do. Both science and industry worked under the direction of the United States Army, which achieved a unique success in managing so diverse a problem in the advancement of knowledge in an amazingly short time. It is doubtful if such another combination of could be got together in the world. What has been done is the greatest achievement of organized science in history. It was done under high pressure and without failure."*

While each condition is embodied well within the Manhattan Project structure except perhaps the need to influence and manage the world external to the program like a campaign or a change movement (Condition #5). Largely this world was the military machine but not the general global populace who did not know of what was going on.

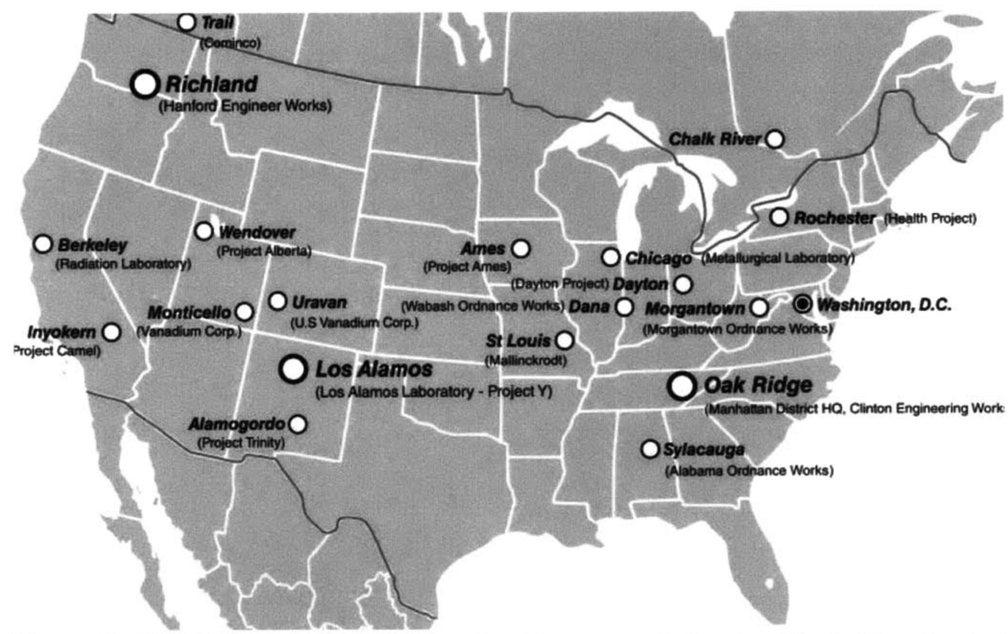


Figure 5.18: The network of site involved in research for the Manhattan Project.

It can be argued that Condition #5 was really manifested after the dropping of the bombs on Hiroshima and Nagasaki themselves in 6th and 9th August of 1945. On 12th August 1945, the US government released the detailed facts of the Manhattan Project to the public through the publication of the Henry D. Smyth report called *Atomic Energy for*

Military Purposes. The advent atomic weapons and the role they played in the war closing down and the Japanese surrender yielded positive sentiments from a large majority of the US population (Kelly, 2007). But was detailed accounts of the horrific repercussions and effects on civilians in Japan of the dropping the bombs became evident (most specifically from the John Hershey's book *Hiroshima* published a year after the initial event) public sentiment quickly became divided. Oppenheimer himself soon after the conclusion of the war called atomic energy as "too revolutionary to consider in the framework of old ideas." Excerpts from Oppenheimer's November 1945 speech given to the demonstrates a mature understanding of the dynamics of change we have discussed in earlier sections.

> *"It is not possible to be a scientist unless you believe that it is good to learn. It is not good to be a scientist, and it is not possible, unless you think that it is of the highest value to share your knowledge, to share it with anyone who is interested. It is not possible to be a scientist unless you believe that the knowledge of the world, and the power which this gives, is a thing which is of intrinsic value to humanity, and that you are using it to help in the spread of knowledge, and are willing to take the consequences. And, therefore, I think that this resistance which we feel and see all around us to anything which is an attempt to treat science of the future as though it were rather a dangerous thing, a thing that must be watched and managed, is resisted not because of its inconvenience – I think we are in a position where we must be willing to take any inconvenience – but resisted because it is based on a philosophy incompatible with that by which we live, and have learned to live in the past.*
>
> *There are many people who try to wiggle out of this. They say the real importance of atomic energy does not lie in the weapons that have been made; the real importance lies in all the great benefits which atomic energy, which the various radiations, will bring to mankind. There may be some truth in this. I am sure that there is truth in it, because there has never in the past been a new field opened up where the real fruits of it have not been invisible at the beginning. I have a very high confidence that the fruits – the so-called peacetime applications – of atomic energy will have in them all that we think, and more. There are others who try to escape the immediacy of the situation by saying that, after all, or has always been very terrible; after all, weapons have always gotten worse and worse; that this is just another weapon and it doesn't create a great change; and that they are not so bad; bombings have been bad in this war and this is not a change in that – it just adds a little to the effectiveness of bombing; that some sort of protection will be found. I think that these efforts to defuse and weaken the nature of the crisis make it only more dangerous. I think it is for us to accept it as a very grave crisis, to realize that he's atomic weapons which we have started to make a very terrible, that they involve a change, that they are not just a slight modification: to accept this, and to accept with it. The necessity for those transformations in the world which will make it possible to integrate these developments into human life.*

As scientists I think we have perhaps a little greater ability to accept change, and accept radical change, because of our experiences in the pursuit of science. And that may help us – that, and the fact that we have lived with it – to be of some use in understanding these problems.

It is clear to me that the wars have changed. It is clear to me that if these first bombs – the bomb that was dropped on Nagasaki – that if these can destroy 10 miles, then that is really quite something. It is clear to me that they are going to be very cheap if anyone wants to make them; it is clear to me that this is a situation where quantitative change, and a change in which the advantage of aggression compared to defense – of attack compared to defense – is shifted, with his quantitative changes all the character of a change in quality, of a change in the nature of the world."

In these words, Oppenheimer clearly outlines the transition from the design to the change phases and lays out a principled role of the architects in helping shape that change. He also recognizes that the suddenness and immediacy with which the world was thrust into the Atomic Age and how it was brought there is an immense change that should not be dealt with in a polyanna way but in a factual way dealing with the severe implications of this massive global sea change. He goes onto say to the scientists of Manhattan Project:

"The point is that atomic weapons constitute also a field, a new field, and a new opportunity for realizing preconditions. I think when people talk of the fact that this is not only a great peril, but a great hope, that this is what they should mean. I do not think they should mean the unknown, though sure, value of industrial and scientific virtues of atomic energy, but rather the simple fact that in this field, because it is a threat, because it is apparel, and because it has certain special characteristics, to which I will return, there exists a possibility of realizing, of beginning to realize, those changes which are needed if there is to be any peace...

I think that in order to handle this common problem there must be a complete sentence of community responsibility. I do not think that one may expect that people will contribute to the solution of the problem until they are aware of their ability to take part in the solution. I think that it is a field in which the implementation of such a common responsibility has certain decisive advantages. It is a new field, in which the position of vested interests in various parts of the world is very much less serious than in others. It is serious in this country, and that is one of our problems. It is a new field, in which the role of science has been so great that it is to my mind hardly thinkable that the international traditions of science, and the fraternity of scientists, should not play a constructive part. It is a new field, in which, just a novelty in the special characteristics of the technical operations should enable one to establish a community of interest which might almost be regarded as a pilot plant for new type of international collaboration. I speak of it as a pilot plant because it is quite clear that the control of atomic weapons cannot be in itself. The unique and of such operation. The only unique and can be a world that is united, and a world in which war will not occur. But *these things don't happen overnight and in this field, it would seem that one could get started, and get started without meeting those insuperable obstacles which history has so often placed in the way of any effort of cooperation. Now, this is not an easy thing, and the point I want to make, the one point I want to hammer home, is that an enormous change in spirit is involved...*

I think this is another question of importance: that is, what views will be held on these matters and other countries. I think it is important to realize that even those were well-informed in this country have been slow to understand, so do believe that the bombs would work, and then slow to understand that there working would present such profound problems. As I have said, had for a long time. The feeling of the most extreme urgency, and I think maybe there was something right about that. There was a period immediately after the first use of the bomb when it seemed most natural but a clear statement of policy, and the initial steps of implementing it, should have been made; and it would be wrong for me not to admit that something may have been lost, and that there may be tragedy in that loss. But I think that the plain fact is that in the actual world, with the actual people in it, it has taken time, and it may take longer, to understand what this is all about.

I think that we have no hope at all. If we yield our belief in the value of science, and the good that it can be to the world to know about reality, about nature, to attain a gradually greater and greater control of nature, to learn, to teach, to understand. I think that if we lose our faith in this we stop being scientists, we sell out our heritage, we lose what we have most of value for this time of crisis.

But there is another thing: we are not only scientist; we are men, too. We cannot forget our dependence on our fellow man. I mean not only our material dependence, without which no science would be possible, and without which we could not work; I mean also are deep moral dependence, in that the value of science must lie in the world of man, that all our roots lie there. These are the strongest bonds in the world, stronger than those even that bind us to one another, these of the deepest bonds – that bind us to our fellow men."

Much can be said about the goodness or badness of the Manhattan Project in the over 70 years since its inception. Individuals have cited a myriad of negative global impacts from this effort. The most striking is the horrifying effect the bombing had on individuals who were the innocent victims of the bombing itself, in ways that the world had never seen. Others cite the lack of a need to even utilize the bomb at all, and posit that Japan was on the verge of surrender after the Soviet Union declared war against them (Kelly, 2008). People cite the environmental impacts of the waste and residual materials from the Manhattan and subsequent hydrogen bomb projects some which are still posing incredible ecological threats in places like the Columbia River Gorge in Hanford, Washington (Chowdhury, 1997). Lastly individuals cite the introduction of a vicious new way of conducting war at a scale and magnitude that then presented a dire threat to global security (and still does) during and after the Cold War.

On the flip side, many have cited the positive aspects of the project. There is a large population of researchers that believe the facts support the idea that the dropping of the atomic bomb actually did end the war and ended up saving many thousands of Allied soldier's lives as well as the lives of civilians in Japan from conventional bombing. Others point to the fact that the original premise of Oppenheimer that the creation of a weapon so horrible that it would bring an end to all war may have in some ways been valid. Another nuclear weapon was never used against another nation-state since after the Nagasaki bombing, often as the concept of Mutually Assured Destruction (MAD) greatly reducing the total number of people who could have potentially been killed in war. Perhaps some of the most beneficial legacy of the Manhattan Project is a structural and organizational one. The Los Alamos National Laboratory (LANL) is the greatest concentration of scientists in any location on in the world. It serves a critical security mission for the US and the world at large in being a scientific and technological steward for the world's nuclear stockpiles and working on nuclear nonproliferation (LANL, 2008). It has spent a large part of its efforts in helping to undo many of the misgivings of the past generations, for example having projects that direct science to nuclear waste remediation utilizing clean hydrothermal processing techniques (Buelow et al, 1998; Chowdhury, 1997) or the detailed research into viable alternate energy sources beyond nuclear. It brings a unique set of capabilities to the planet, direct off-shoots and growth from its original roots including computational fluid dynamics, proton radiography, nuclear materials and chemistry and space sciences creating spin-off innovations like global climate modeling, nanostructured materials, fuel cell catalysts, and genetic imagery exploitation. These innovations have allowed additional mission elements to around energy security and global threat reduction. Most importantly perhaps, LANL in the spirit of its original foundation in 1943, the lab has taken on 8 grand challenges for science (LANL, 2008):

<u>*Challenges addressing science*</u>

Beyond the standard model
Superconductivity and actinide science
Complex systems
Fundamental understanding of materials

<u>*Challenges addressing mission*</u>

Carbon neutral fuel cycle
Ubiquitous sensing
Boost physics

<u>*Overarching capability*</u>

Information science and technology

These work in concert with the capabilities defined. The progress of the lab since 1943 outlines perhaps the initially under-conceived potential to continue positive work and leave a legacy in the form of an impactful organizational construct and capabilities to address modern challenges from the Manhattan Project itself. Perhaps in many ways

Oppenheimer alluded to these very facts and needing to take head on the positive and negative implications of being in the Atomic Age.

While the debate on the positive or negative aspects of the Manhattan Project will continue to be a facet of the human debate for the rest of our existence, it is hard to deny the cross-sector model and technical achievement of the Manhattan Project. In our challenge level scale it ranked the highest, and in many ways, presented a unique difficulty in itself, and if the post-bomb Atomic Age change dynamic was added to the analysis, the challenge level would surely score very close to a 7. The world literally underwent a step-change in the course of a day and contemporary history has not shown that in any of the other endeavors listed or studied.

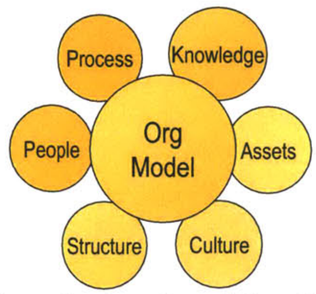


Figure 5.19: Organizational model and its components.

Ultimately what the Manhattan Project represents in our study is an unique archetype for a situation where the 11 necessary conditions are met and met at a high level. It provided a scheme and way to put into operation a system that embodies the 11 conditions. It provides a blueprint that brings the 11 conditions and connects them in an organizational sinew and places them in an integrated way into the real world and does so successful from a technical perspective. It is the operational model of the Manhattan Project that is of key interest to us. An organizational model and its components are shown in Figure 5.19. This model is an adaptation from work done my Donald Hambrick (Hambrick, 2009). In the Manhattan Project we find certain ways whereby processes, structures, knowledge, assets, people and culture come together around the 11 conditions and makes them work in concert. Each of the 11 conditions colors a certain aspect or aspects of the organizational model elements in heightened ways for the Manhattan Project. We find that as we march down the list of the endeavors listed on Table 5.1 we find that each is similar but perhaps one step shy from the architecture of the Manhattan Project. Notably 9 of the top most challenging 10 endeavors have the same organizational constructs and often analogous architectures of process, structure, knowledge, assets, people and culture to the Manhattan Project.

The question to be addresses then for our larger study becomes, is the Manhattan Project construct the optimal construct for operationalizing the 11 conditions? The short answer is "no" but it certainly is a viable model. It may not be the MOST viable organizational construct but it provides an initial blue print from which incremental modifications can be made to better fit the new global challenges. This approach has been explored by Freeman and Soete in their work on industrial innovation (Freeman et al, 1997). They talk about large "mission-oriented" projects of the past and compare them to how those same mission-oriented projects differ in contemporary times and these recommendations and observations can be translated from how they are different compared to the old paradigm. These differences are shown in Table 5.5.

Characteristics of old and new "mission-oriented" projects	
OLD: e.g. defense, nuclear, aerospace	NEW: eg. environmental technologies
The mission is defined in terms of the number and type of technical achievements with little regards to their economic feasibility.	The mission is defined in terms of economically feasible technical solutions to particular environmental or global problems.
• The goals and the direction of technological development are defined in advance by a small group of experts.	• The direction of technical change is influenced by a wide range of actors including government, private firms and consumer groups.
• Centralized control within a government administration	• Decentralized control with a large number of agents involved
• Diffusion of the results outside the core of participants is of minor importance or actively discouraged.	• Diffusion of the results is a central goal and is actively encouraged.
• Limited to a small group of firms that can participate owing to the emphasis on a small number of radical technologies.	• An emphasis on the development of both radical and incremental innovations in order to permit a large number of firms to participate.
• Self-contained projects with little need for complementary policies and scant attention paid to coherence.	• Complementary policies vital for success and close attention paid to coherence with other goals.

Table 5.5: The characteristics of old and new "mission-oriented" projects (Freeman and Soete)

The descriptions of the old and new mission-oriented projects given in the Table 5.5 are "shadows" of the actual organizational model that produced them. Knowing in detail now the organizational model of the Manhattan Project and its legacy organization of the Los Alamos National Laboratory and how it embeds the 11 conditions, it is clear how the descriptions on the left are accurate. We have a picture of the organizational model, and the descriptive shadow it might place of the old paradigm described by Freeman and Soete. What we do not have is an idea of sort of an effective organizational model (with processes, structures, knowledge, assets, people and culture) would produce the shadow described in the "new" column. Is there a viable organizational model that allows for the 11 conditions to be embedded AND that would look like the description given by the right hand column? This is the topic of the Section 6, where we study an endeavor and a model at close range and the of Section 8 where we describe how an organizational model can be built for global challenges and compare it with current proposals.

SECTION 6: ACTIVE CASE STUDY AND DIRECT APPLICATION OF THE NECESSARY CONDITIONS MODEL

In order to test the formulation of the assessment tool developed we have chosen to study at close range an actual large-scale socio-technical solution being implemented in a global organization that spans 91 different locations around the world. Indeed, the formation of this assessment tool has been in large part an iterative exercise whereby direct leadership and involvement in this large-scale socio-technical change in this multinational enterprise by the author has helped inform and perfect the different components of the assessment model that was initially generated from thematic studies and bibliographic analysis from management science texts. This multinational company will be hereby referred to as "The Company". The following is an excerpt from the Company's 10K submission to the SEC.

> *The Company is a global health care company that delivers innovative health solutions through its prescription medicines, vaccines, biologic therapies, animal health, and consumer care products, which it market directly and through its joint ventures. The Company's operations are principally managed on a products basis and are comprised of four operating segments, which are the pharmaceutical, animal health, consumer care and alliances segments, and one reportable segment, which is the pharmaceutical segment. The pharmaceutical segment includes human health pharmaceutical and vaccine products marketed either directly by the Company or through joint ventures. Human health pharmaceutical products consist of therapeutic and preventive agents, generally sold by prescription, for the treatment of human disorders. The Company sells these human health pharmaceutical products primarily to drug wholesalers and retailers, hospitals, government agencies and managed health care providers such as health maintenance organizations, pharmacy benefit managers and other institutions. Vaccine products consist of preventive pediatric, adolescent and adult vaccines, primarily administered at physician offices. The Company sells these human health vaccines primarily to physicians, wholesalers, physician distributors and government entities. The Company also has animal health operations that discover, develop, manufacture and market animal health products, including vaccines, which the Company sells to veterinarians, distributors and animal producers. Additionally, the Company has consumer care operations that develop, manufacture and market over-the-counter, foot care and sun care products, which are sold through wholesale and retail drug, food chain and mass merchandiser outlets in the United States and Canada.*

The socio-technical innovation that is being propagated is a system that better helps to seed new technologies that are needed to transform the entire global manufacturing operation in large scale to be better suited for the future healthcare conditions and situations. Some of these innovations are direct physical technologies and others are social technologies but most are combinations as we have been dealing with in this paper.

Before we progress much further we must validate two things. We will call this Endeavor 2011. The first is that the socio-technical solution being designed fits all the attributes of the complex human endeavors

In order to underscore the validity of a close range study of this assessment tool within the bounds of a multinational corporation, we must first demonstrate that it is a fair assumption that this endeavor is indeed high on the list of difficulty as we have defined in the earliest formulation of design and adoption difficulty and that the multinational corporation can serve as an adequate future representation of the world at large. In calculating the 5.06, 576 and 110.

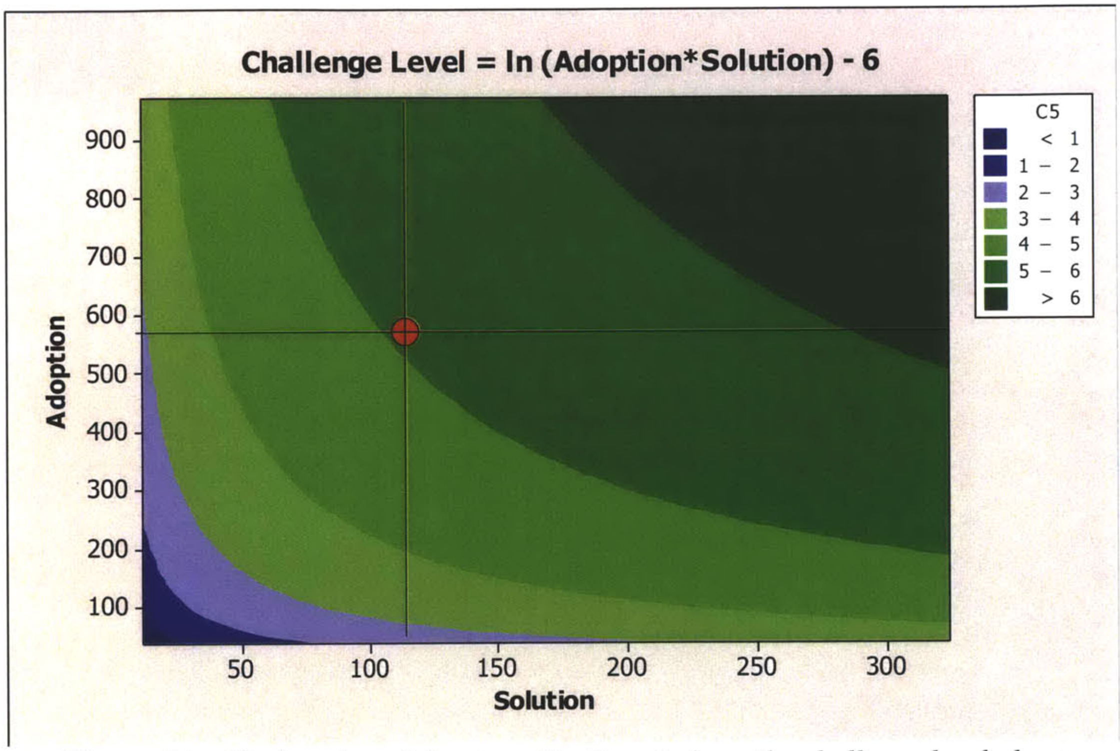


Figure 6.1: The location of direct application study on the challenge level phase diagram

While not entirely in the greater than 6 zone, this was one of the most transformational initiatives occurring at the company and thus viewed as a close enough test case to observe directly and modify courses of action in situ. While there were initiatives in the Company that were in the Zone 6 and above area, it was felt that the ability to influence such initiatives was not that high and thus would not provide the adequate level of scrutiny and control. To provide about as much of a control as can be allowed a retrospective analysis was done on four other transformational initiatives conducted in the Company between the years 2003 and 2011. The concept here is too test the principles of necessity and optimality at close range. All subjects in the study were subject to the adequate and appropriate COUHES norms and guidance as indicated by MIT's code of conduct for research. It will be shown how the four initiatives studied provide a confident design space with four points and conditions distributed about the chart above.

The endeavor studied was the implementation of enterprise level technology roadmaps that will drive decade long transformation and innovation at all levels of the global operations. Technology roadmapping is a process that has been applied effectively to the identification, selection, acquisition, development, exploitation, and protection of technologies in a variety of industries. In this section we describe an approach taken at the Company that allows this technique to drive process systems activities across a size scale that spans a global manufacturing operation with hundreds of connected supply chains and time scales that span multi-years into the future.

When driven at the global operation level, technology roadmapping provides the only viable way to align thousands of technology, organizational and business model changes to transform systematically and coordinate transformational activities across the organization. This is especially critical at the Company where global operations deal with the manufacture and distribution of medicines and vaccines that preserve or improve human life and animal health. For the purposes of this initiative, we have defined technology as a system comprised of scientific/technical knowledge, processes and equipment that is used to accomplish a specific goal. The knowledge encompasses the understanding of fundamental principles and relationships that provide the foundation of the technology. The processes are the procedures, techniques and best practices associated with the technology. The equipment is the physical manifestation of the technology as devices, instruments and machinery. Given this definition, manufacturing technologies are combinations of knowledge, process and equipment that comprise that transforms raw materials into products and delivers them in a useful form to our patients & customers. Additionally, product configurations are changes in format to a product that a customer would see or perceive – for example formulation platforms or packaging configurations that manufacturing technologies enable.

Our approach follows in a fairly linear way. Initially we create global operations level systems views, allowing for holistic management and consideration of systems changes. This creates the visual of the larger system that is the subject of transformation and deployment of technologies. Stakeholder maps are created that account for the external and internal constituencies clearly identifying the key stakeholder groups involved in global systems level transformation. The changing global trends are then mapped inwards from the customer market and societal needs and outwards from the business drivers and requirements from the manufacturer. In this paper, we focus on the some significant shifts in the health and sustainability areas. This stakeholder mapping also allows for the development of key performance indicators (KPIs) for the global system, thus collapsing the trends and drivers identified into workable and measurable goals. These KPIs result in very precise operational definitions around which global operations level changes can be made. During the needs and requirements definition, technology inventories can be created simultaneously by technology subject matter experts that become repositories of internal and external technology efforts and innovations. The two streams of efforts combine when the KPIs, trends and drivers are used to prioritize the technologies in time that are most important. This allows for the initial creation of technology roadmaps. Individual technologies are generally at the single and multi-phase system and process unit level, and thus visualization on roadmaps allow for plant, site and enterprise level integration and planning. Interactions between different global pathways can be analyzed utilizing dependency structure matrix (DSM) analysis. This creates a portfolio of projects that can be managed through maturity by an enterprise-wide technology management process and governance, with information and knowledge being refreshed on an annual basis as the transformation and implementation progresses.

At the very beginning, the design problem needed to be solved starting from a visionary Leader-Architect who then surrounded himself with 6 core individuals who provided initial guidance and intent definition, the burning platform and the compelling destination. This led to the formation of Shell structure for the initiative that allowed for tactical decision and activities (outlined below) with the broader strategic activities that needed to be accomplished that had time horizons at a very large scale (what we would categorize as higher Shells in the Shell model described in Section 4). The mock up of the team structure is shown in Figure 6.2.

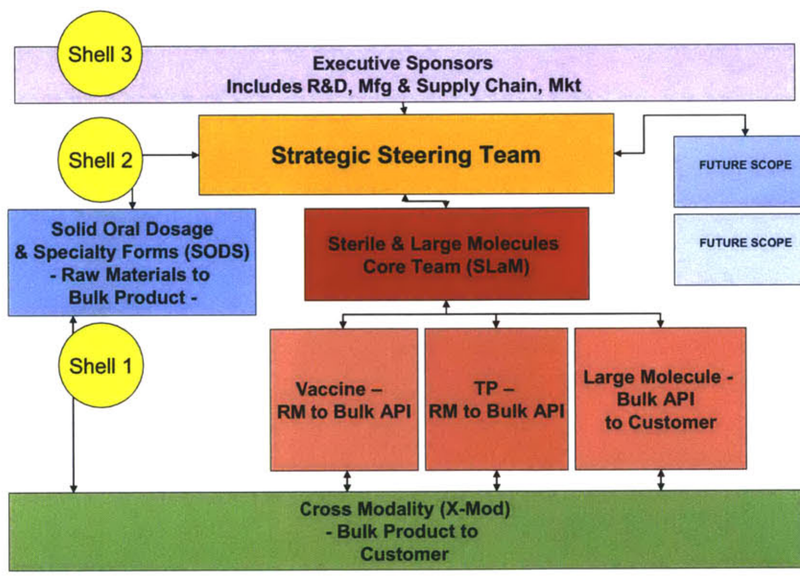


Figure 6.2: Large initiative structure for Endeavor 2011 taking advantage of conditions outlined in Section 4 including Shell segregation.

This allows this construct to parse out the appropriate work in the right time scales and encode the other necessary conditions into the design portion of Endeavor 2011. What follows are the initiative steps that led to the ultimate first phase implementation and success of this Endeavor.

Global Operations Level Systems Views

A simple schematic of all the possible pathways of manufacturing possible at the global operations level was created. This is depicted in Figure 6.3 below.

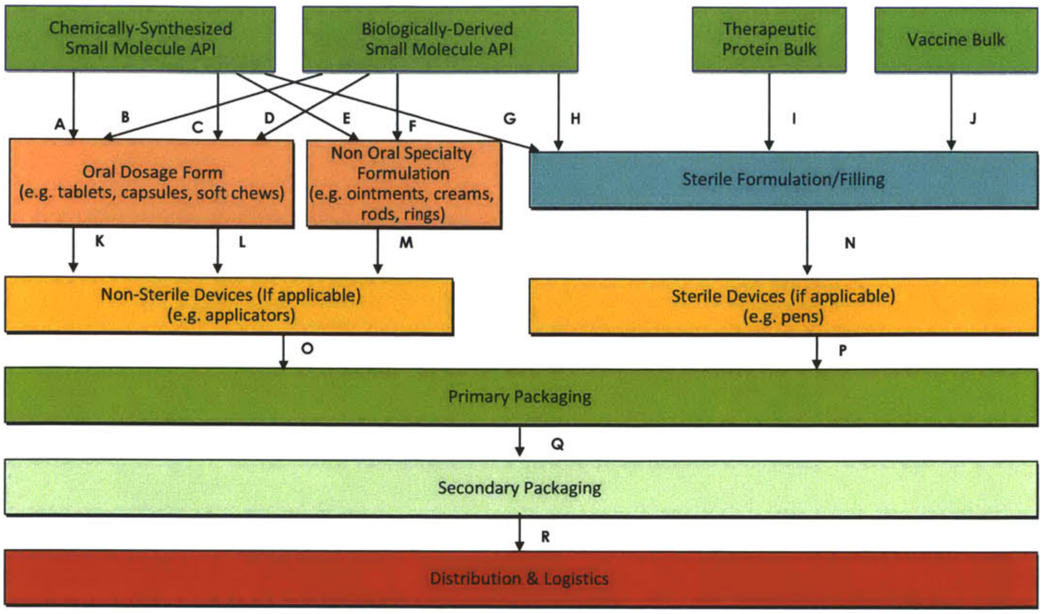


Figure 6.3: Global operations level system view

In this global view, process unit systems up to plant scales can exist within each box, while site and enterprise level integration occurs along pathways defined by connections of different boxes. An example of a pathway is AKOQR, which represents the pathway for a small molecule pharmaceutical oral dosage form. It is clear that from even this view, PSE models for enterprise optimization such as those discussed by Sahinidis (Sahinidis et al, 1989) or Grossman and Biegler (Biegler et al., 1997) can be applied to pathways such as AKOQR, and that the evolution of technologies within any given node of box would inform the variables, constants and coefficients of the models from the current pathways to future pathways. Each processing unit box can be further blown out as necessary, but the overarching scheme allows for taxonomy of future roadmaps for each node and each pathway.

Stakeholder maps, trends, drivers and key performance indicators

Having a clear way of representing all the stakeholders of the global operation is incredibly important as it allows for segmentation of needs and ultimate definition of key performance indicators by constituency. A high level stakeholder map from our work is shown in Figure 6.4

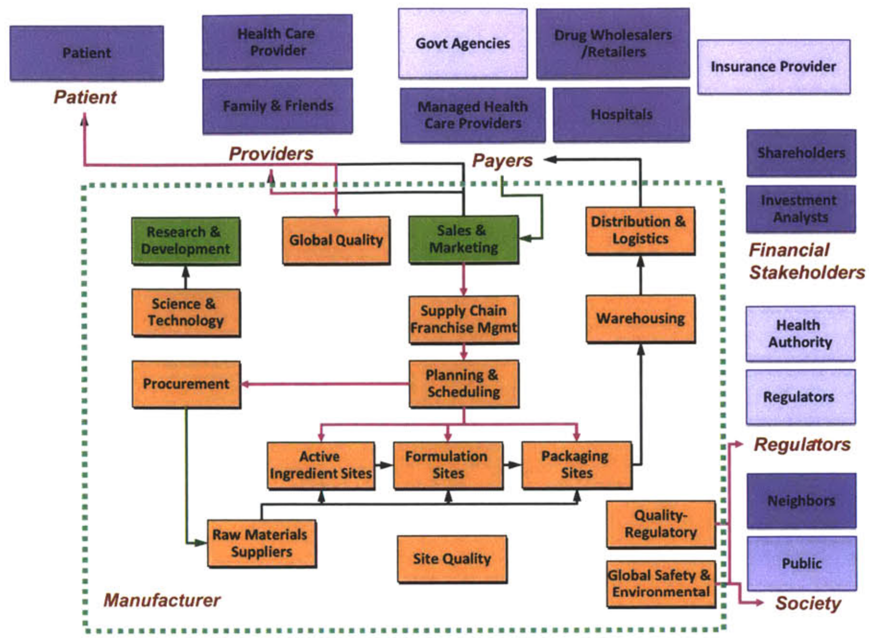


Figure 6.4: Stakeholder map for the global operation

As global operations-level transformation occurs, there are multiple interests that must be met. Patients and consumers must benefit from the appropriate use of our products and services and challenges such as affordability and adherence must be met. Different configurations that allow for convenient and safe use as well as protect the product from human and environmental threats must be introduced. On the other side of the stakeholder map, we serve our society, from the local communities in which we operate to the national and international levels, by supporting and promoting environmental sustainability. This leads to processes designed to be green with respect to emissions and waste and sustainable packaging designs and configurations.

It is important to reflect the needs and requirements of the various stakeholders in precise terms, with operational definitions and maps that can establish precise sub-factors that can be targeted by the global operation for improvement. Figure 6.5 is a generic global operations level stakeholder needs and requirements mapping that shows a stylized representation of the stakeholder, KPI, trend and driver mapping.

MAJOR PARAMETER		KEY PERFORMANCE PARAMETER	MEASURE DEFINITION	STAKEHOLDER WHO CARES	SAMPLE TRENDS & DRIVERS FOR THE NEXT 5 YEARS
PRODUCT	A winning product fashioned with the customer value drivers in mind and continues to deliver this value consistently.	Safety & Tolerability	The safety profile of the medicine.	Patient, Provider, Payer, Regulator	More potent compounds
		Efficacy	How effective is the medicine in effecting the disease target, generally measured by bioavailability over time.	Patient, Provider, Payer, Regulator	Variety of different dosage forms to achieve delivery optimums
		Features	Attributes that signify the non-biological elements of the product, like integrity and elegance of the medicine, the ease of use of the packaging etc.	Patient, Provider, Payer, Regulator	Increased set of market and customer-specific requirements
PROCESS	Sustainable and profitable business/manufacturing system to create and deliver the product robustly, wherever they are needed while building and leveraging institutional wisdom seamlessly.	Manufacturing Efficiency and Robustness Measures	All the manufacturing parameters that are part of being a world class supplier including inventory stock turns, process capability (CpK), overall equipment effectiveness (OEE), right first time (RFT), on time in full (OTIF), and cycle times.	Manufacturer, Regulator	Need to do substantially better in all manufacturing effectiveness measures
		Standard Cost to Make Product	The manufacturing cost to create a certain number of units of the product.	Manufacturer	Appropriate reductions to assit with affordability of medications for more customers
		Flexibility to Continuously Improve	The measure of how rigid or flexible the process is to learning and then instituting improvements based on that learning.	Manufacturer	The need for flexible process technologies are going
		Sustainability and Environmental Factor	The inherent operational safety and the green-ness or environmental friendliness and sustainability of the process.	Manufacturer, Society, Regulator	Much greater global need for on green sustainable solutions
		Global Access	Increased global access for medicines is important and this parameter represents the technologies ability to be operable in various markets around the globe.	Patient, Society, Manufacturer	Desire to expand access to previously unserved patients and customers
		Scalability and Continuity of Technology from R&D to Manufacturing	This measures the continuity of the technology from bench scale and pilot scale models to manufacturing allowing for knowledge to be built over time and across different products using the same platform.	Manufacturer, Regulator	The need to have and demonstrate continuous learning from development through to manufacturing is vital

Figure 6.5: Stylized stakeholder, KPI, trend and driver mapping

Technology inventories

While the work of defining key performance indicators are being established for the technologies, parallel work can and should be occurring to gain common and universal enterprise level visibility to all technologies being considered or potentially of interest. An important connection between advances in technology achieved at local levels in the enterprise and the higher level technology strategy should be the development and maintenance of a technology inventory. The technology inventories should be a primary reference source whenever an effort to resolve a stakeholder-driven set of needs or requirement via manufacturing technology is undertaken. The inventory serves as one avenue to connect technology advances in manufacturing, research and all manufacturing businesses to the customers and business. Leaders of technical organizations should assign functional areas to have one or more representatives keep the technology inventory current so that it may be a continuously useful tool for technology roadmapping. Local groups in research and manufacturing can have updating the inventory as a standing objective for technologies in their scope of work. We have found that customer field visits, and reports from conferences, visits to partner companies and industrial collaborations may serve as key sources of contributions to the inventory. Individuals within each area of the enterprise should appoint an appropriate function or group of individuals to periodically check to ensure the inventory is kept current, at least, on an annual basis.

Technology Management Process

A stylized example of a technology roadmap is shown in Figure 6.6, and does not differ much from conceptual examples presented by Phaal (Phaal, 2004) and other manifestations of roadmaps going back to their initial use in Corning and Motorola in the

1980s. The top of the roadmaps are representations of product or business strategies while the bottom represents investments in the most critical enabling technology projects. The horizontal axis represents multi-year transformation time scales while the dotted line ties from the top to the bottom represent a visually simple way of showing the most critical ties. It is important to note that these roadmap visuals constitute a graphical summary of much more complex and interrelated connections that are best managed through multi-domain matrices as will be discussed in the last section.

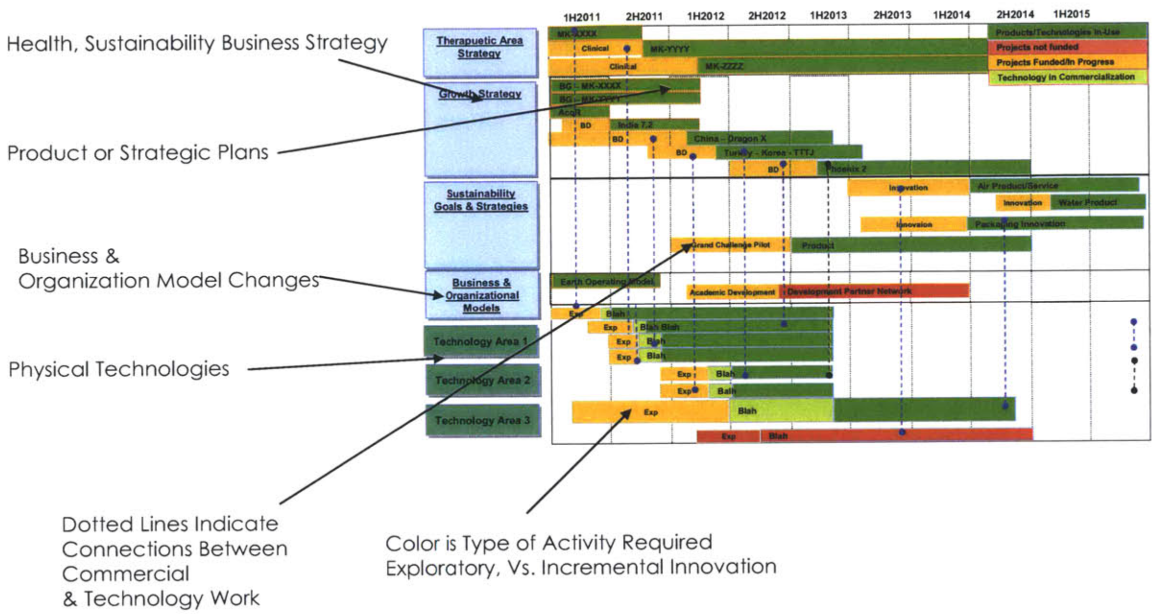


Figure 6.6: Stylized example of a technology roadmap.

The subsystems we have spoken of so far become a part of an integrated technology management process that has these roadmaps at the center, and this concept we have depicted in Figure 6.7. We have chosen to adopt the European Institute of Technology Management (EITM) definition of technology management as that which "addresses the effective identification, selection, acquisition, development, exploitation and protection of technologies (product, process and infrastructural) needed to maintain (and grow) a market position and business performance in accordance with the company's objectives." (Phaal, 2004). This must be managed by an organizational structure that has clear accountabilities and decision rights established. Most importantly, an overarching ability of tracking and responding to process health metrics and realization indicators are extremely important. Each section and its roles are described.

F1 – Technology inventory system – This part of the process ensures that the enterprise can consistently track and update the technologies it has in its inventories from the inside and outside as the business learns more. The sub-process gives access to all technologists to help maintain and access these inventories. Appropriate guidelines for an intellectual property strategy are embedded in this section.

F2 – Product planning system – Access for the latest product plans for every health area and market are embedded here. The means of transforming these product plans into a way the technology roadmaps can consume and use them are defined in this sub-system.

F3 – Customer & business needs/reqts system – It is critical that a firm link is created between the clinical and marketing portions of the business and the customer need-sensing and translation processes are established so that observations can be translated into business requirements and goals. This sub-system also assures that we stay in touch with the business needs and requirements that are independent of customer needs.

P1 – Technology roadmap mgmt – This part of the system establishes how the enterprise manages the actual roadmaps, including gathering changing information, augmenting investment choices, socializing the recommendations, and making decisions on the overall maps and investments. The maps are made visible and visualized on an ongoing basis.

P2 – The gated technology process – The mapping of technology and technical systems to roadmaps allows for global tracking of technologies at each stage of maturity. This is an important concept as different investment postures need to be taken based on different maturity states of the technologies. A clear map of the decision rights at all levels of the enterprise for progressing technologies through must be created, the broader and more externally facing the technology is, the more challenging decision rights can become. Additionally, the enterprise must account for technologies that "pop in" at a gate, that is acquired from the outside or working with a partner. Each gate should have the standard ways to kill projects as well as clear way to map the overall health of the process.

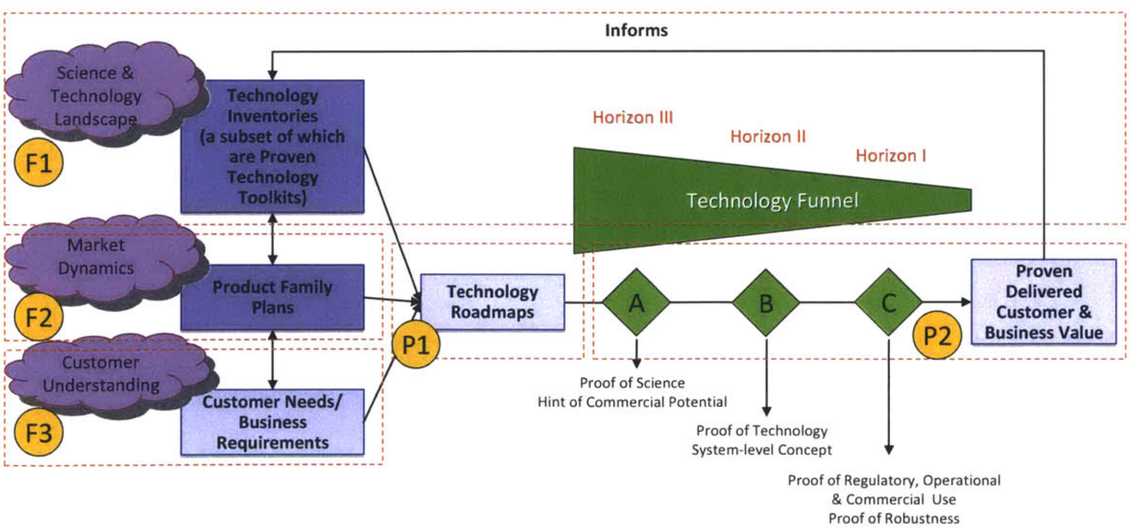


Figure 6.7: Conceptual design of an enterprise level technology management process.

The progression of technologies through the various phases of maturity is critical and linking technology development with the knowledge and capability level of the organization is vital. In this we have proposed using horizons of maturity (Cournoyer, 2003, Chowdhury, 2009, Kukura, 2012). Horizon I technologies refer to incremental improvements in currently commercialized or near commercialized technologies. They are implementable in the near term. Horizon II technologies are in the middle part of the adoption curve (potential technology), the physical principles have been demonstrated either in our industry or elsewhere - we need to adapt the solution for our needs. These are medium term solutions 2-3 years out. Horizon III technologies are much further out and likely the physical principles have not yet been demonstrated. They require some fundamental knowledge work and are a ways from being commercialized. These are longer term solutions.

This maturity level assessment, which is also depicted in Figure 6.6 in the part of the diagram labeled the "technology funnel", can be married up with a needs assessment. As the various stakeholder needs, and for our purposes those that contribute to transforming human health and driving sustainability globally, some will be well articulated (i.e. a problem looking for a solution) and others will not be (i.e. a solution looking for a big way to impact a problem). As we assess transformation at a global operational level, it is important that our efforts have a combination of these types of technologies and these types of defined value drivers. These dual dimensions and the trade space that is created by examining them are represented in Figure 6.8.

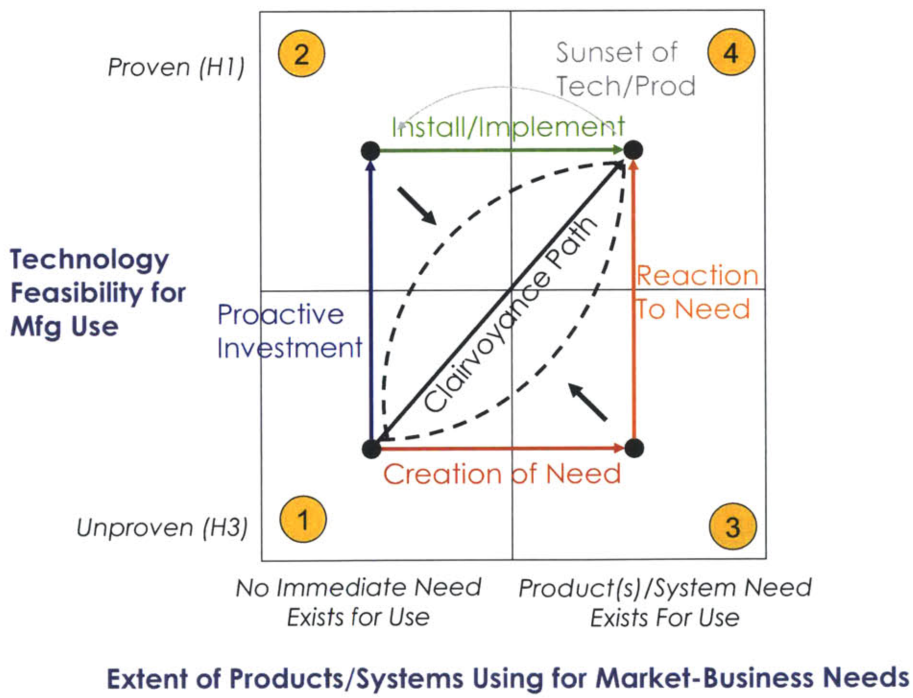


Figure 6.8: Technology Maturity by Extent of Need

In the y-axis, the technology maturity as represented by the different horizons is show while the extent of known and identifiable need is shown in x-axis. Technologies when considered theoretically can traverse from zone 1 to zone 2, where we make proactive investment in a technology without a well articulated need or move from zone 2 to zone 3 where we are implementing a proven technology as a need is articulated. They can theoretically traverse from zone 1 to zone 3 where we work to create a need for an unproven technology or (where most mental models around technology development reside), move from zone 3 to zone 4 where we develop a technology for a particular need. In reality technologies traverse this trade space in multiple and diverse trajectories and at different speeds. They are can start within any zone and can stay within a zone and never go anywhere and die. The idea of technology roadmapping as a means to build large scale systems or transform them essentially looks to solve the most difficult problem of moving technologies from zone 1 to zone 4 in a more methodical, integrated and predictive way. We represent this concept in the diagram as the "path of clairvoyance". Theoretically, well fashioned roadmaps that are refreshed with technical knowledge would deliver a straight line from zone 1 to zone 4. In reality this is impossible, but this thinking does provide some helpful principles as the enterprise puts in place an overarching technology process.

The Adoption Process

To illustrate the difference between incumbent technologies and new technologies we will focus on the application of creating an oral dosage form in the formulation creation space using either incumbent technology like roller compaction, wet granulation, direct compression, or liquid filled capsule technology to new or emerging technology like hot melt extrusion, spray drying, or nanomilling. Figure 6.9 demonstrates some possible ways adoption can be measured by each user segment using the % of total investment method.

CUSTOMER/USER SEGMENT					
Product Developer Chemist / Formulator	Clinical Researcher	On-Site Operations	Manufacturing Supply Chain Partners (Internal/External)	New Business Development	Regulators
ADOPTION MEASURES					
% of total products in the pipeline that can be made bioavailable using specific PMTP	% of total clinical and other non-commercial finished supplies provided from the PMTP	% of total volume that is produced using PMTP from any given site	% of product supply chains that are built around the PMTP	% of growth/new business or new revenue, market share that is services by PMTP	% of total FTEs at regulatory agencies that can review/inspect the PMTP
% of total $ or FTEs in the chemistry/formulation R&D budget used in maintaining/renewing the PMTP		% of total $/FTE resources in manufacturing budget	% of manufacturing partnership funds dedicated to PMTP	% of total SKUs serviced by the PMTP	% of approved filings that contain PMTP

Figure 6.9: Proposed adoption measures by user/customer segment.

To demonstrate how one can map out user behaviors, adoption and diffusion mechanisms, let us describe the Product Developer, Chemist/Formulator user group. For this user segment, knowledge and past experience is extremely important for ease of use. There is a comfort level that comes with having myriads of datasets from past projects about how the particular raw materials and excipients behave when processed in the technology during processing. The job that the product developers ultimately want done is to figure out how to get certain product properties consistently by dialing in certain processing parameters and operational rules in the technology. The more prior knowledge and proven, experimental data they have, the better it is. However, the percentage of low solubility, high molecular weight, lipophilic APIs are increasing to become almost 40% of the all new drug pipelines from a low of only 20% only 5-8 years ago. (Peters, 2008). This is a situation of constraints, where the ubiquitous technologies are just not up to par in being able to deliver the needed functionality. So while the incumbent technologies of roller compaction win in the today in terms of the adoption indicators, the newer technologies of spray drying, hot melt extrusion, or nanomilling may indeed be able to provide more functionality given the new mix of chemical entities we are seeing. One would expect to see that over time the adoption of the new technologies vs. the incumbent technologies would look something like Figure 6.10. The acronym PMTP stands for pharmaceutical manufacturing technology platform.

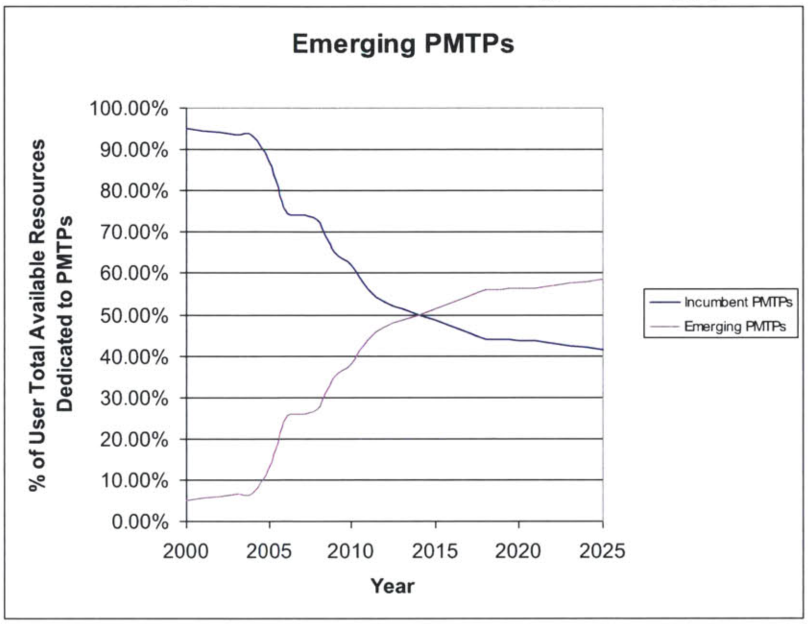


Figure 6.10: Simulation of adoption of emerging PMTPs as compared to incumbent PMTPs from the product developer, chemist/formulator user segment.

In order to able to predict the dynamics of adoption as shown in Figure 6.10, it is important to consider the various customer and user inputs. Davies classifies the following customer/user inputs when defining the total customer experience and the co-evolution of user needs and technology capabilities (Davies, 2009). These are "User Jobs to be Done", "User Desired Outcomes", "User Constraints". Looking at these, one can draw simple adoption and diffusion mechanisms for each user segment. For Chemists and Formulators, Murray (2008) and Peters (2008) both describe the shift in technology investments. For Clinical Researchers, we can see Scherer (2007), the Preview of Drug Discovery & Development (2008) and van Arnum (2007) shows the clear delineations and mechanisms by which investments are shifting from small molecule PMTPs to more biological oriented ones. In the arena of servicing the On-Site manufacturing segment, Moreton, (2007), Miller (2007) and Shankar (2008) shows clearly that the need for operational efficiency and proven tactics in the adoption of PMTPs into on-site operations. For the Manufacturing Supply Chain, Miller (2008b), talks clearly about the role and expansion of PMTPs into partners and emerging market colleagues. For New Business Development, it is all about how much your PMTP can help the business in attaining new revenue as the primary adoption mechanism as indicated by Miller (2008a). Finally the regulator adoptions are driven by the adoption in primary countries of a particular PMTP followed by reviewer and inspector competency-build in those and secondary countries as shown by Drakulich (2008).

These various adoption and diffusion mechanisms are described in Figure 6.11. Each mechanism is identified as either probit or epidemic, thus informing to some degree the tactics we would need to take to incite adoption in these user groups.

Figure 6.11 (at the end of this section): Adoption and diffusion mechanisms for PMTPs by customer and user segments.

Mapping Accountabilities

In a complex ecosystem of human organizations, it is incredibly important to get the accountabilities to the right place. That right place must indeed be agreed to by the masses. While it is easier to do within the walls of an enterprise, e.g. in the bounds of the Company, it becomes increasingly challenging the larger the organization gets. As a matter of fact, large multinational organizations often mirror the intricacies of the larger world when mapping accountabilities. The Company itself had multiple external contacts, partnerships and academic collaborations, making the process of accountability mapping extremely involved. The first step in the initiative was to create a map of the Company in various "strata" of the Company itself. Strata are defined as layers in the organization that correspond to various levels of aggregation. This is shown in the Figure 6.12 with 5 strata represented. Theoretically, the higher the stratum (higher being in the direction up, that is to lower numbers) the more integrated and concerted action is required.

In the model set up at the Company, there were 5 strata, with Stratum 5 being the lowest functional level of groups and units. For the Company, this is where the majority of the resources in terms of full time equivalent (FTE) employees and monetary funds and equipment comes from. It should be noted that other enterprises may have different wells and sources for funds and people, but it was the case in the Company that the originating points for these things was Stratum 5. The department level, Stratum 4 generally existed between the divisions of R&D, Manufacturing and Supply Chain, or Sales & Marketing. These departments offer resources to integrated teams that usually take the form of the three major forms of organization, being product or customer, regional or geography or technology and these different themed teams are in Stratum 3. These various team flavors usually report into some decision making or execution oversight body, which are shown in Stratum 4. Lastly, at the Company level, there are a few integrated decision making or execution oversight groups, groups that make large company-impacting strategic decisions. Usually this group has two main functions: making big decisions and deploying them to the right strata below them or playing a critical advocacy role in the company.

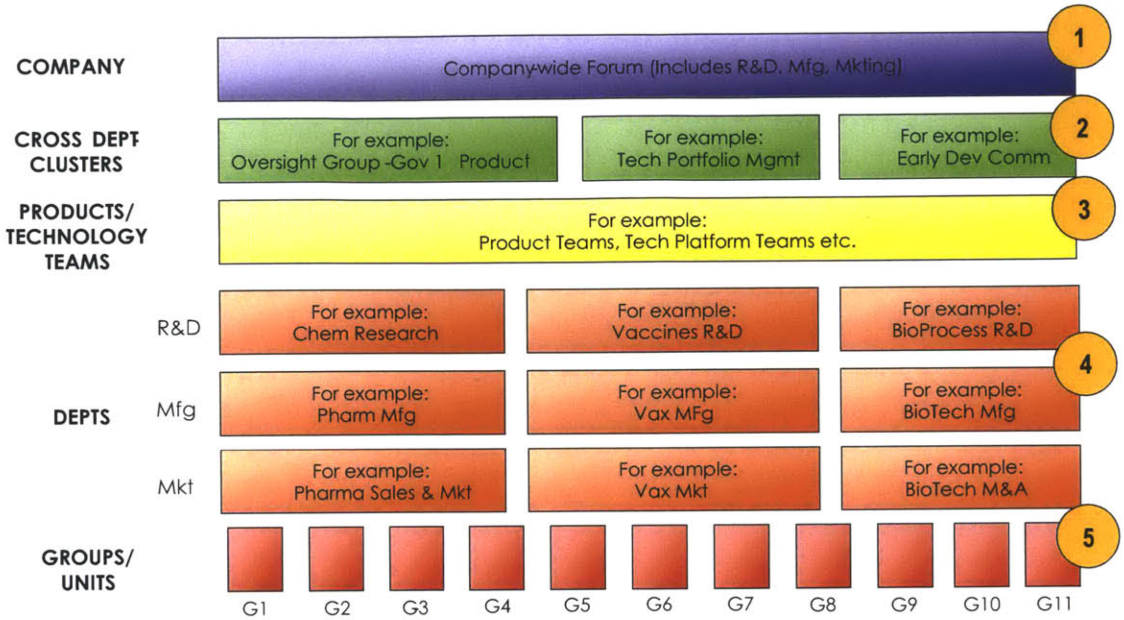


Figure 6.12: Strata model for mapping governance in the Company

One of the most difficult things to do is to map the appropriate trifecta of strategy (decisions, execution and oversight) into these strata levels. A principle when the mapping is highly complex is to think about the following pneumonic:

STRAP = Shuttle To the Right Accountability Promptly

While this is a convenient encoded principle, it does require some tacit or explicit knowledge of the mappings and decision rights. It is important to make this as visible as possible.

In order to do this, the concept of a "scheme" was introduced. A "scheme" is defined as a proposal for strategic **decision making**, **execution** and **oversight** that identifies which groups/individuals will commit the Company to the proposed action and which groups/individuals will provide the resources, funding, expertise and oversight. The sponsor team for the initiative are those approving schemes for some of the most interdependent and difficult technology proposals. A good scheme should demand focus on customers and patients, enable rapid and disciplined decision making, foster collaboration and most importantly drive results. To approve a scheme, the sponsors must think of questions such as:

Do we have the right commercial, market, customer input to the value of the proposal?

Does the scheme place the accountabilities in the right place to execute and carry out the work?

Do we have the right oversight to connect the work across the organization?

Is the oversight group the right one to assess technical and commercial feasibility and abandon or accelerate as needed?

The visual mapping of schemes was accomplished using two valuable frameworks, called RAPID and RASCII. The first which stands for Recommend, Agree, Perform, Input and Decide was crafted by Marcia Blenko (Blenko, 2010) and is a very valuable tool to map decisions up to the point of execution (or the Perform role). The RASCI model is familiar to many from the systems engineering world and serves well to break down the doing. Figure 6.13 shows the breakdown of the RAPID and RASCI as used to define schemes.

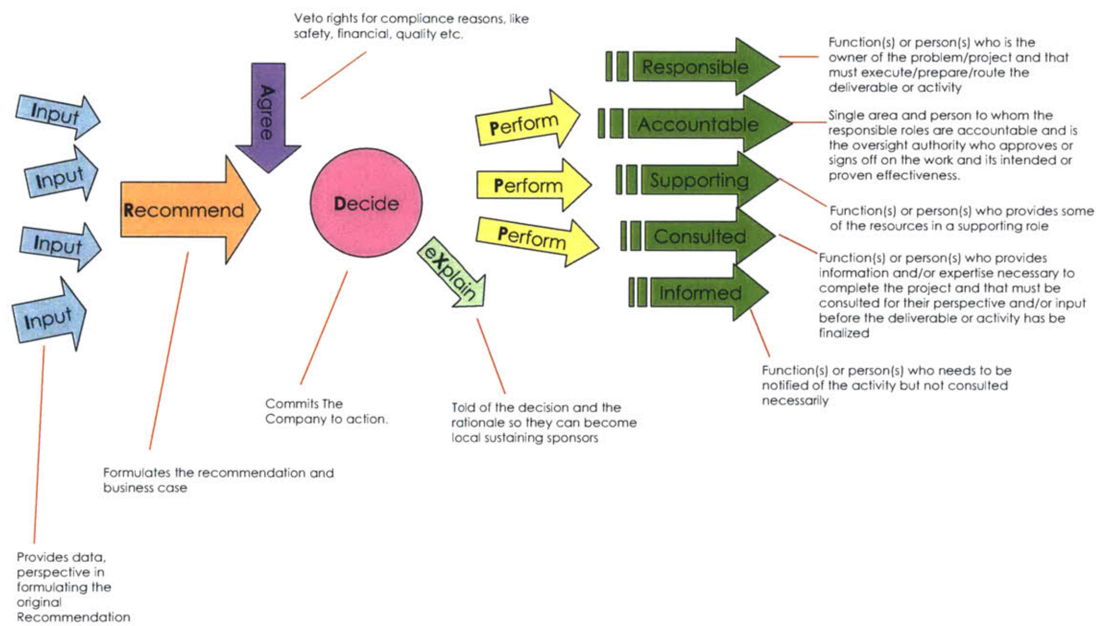


Figure 6.13: RAPID and RASCI models applied to defining decision, execution and oversight schemes (Hobbs, 2007).

It may feel strange to say, but aside from the actual innovations that need be generated in the Company to accomplish this ambitious endeavor, the creation of these schemes are the most paramount to success.

The Technology portfolio and network management

The final leg of the process is to actually manage the technologies efforts that are born of the technology roadmaps. One of the key issues around technology management is the lack of visibility of how different efforts touch each other and need information or data from one another to make a larger, more holistic transformation possible. In helping to manage these interdependencies, the concept of the multi-domain matrix (MDM) has been applied (Crawley et al, 2004). A mock version of an MDM is shown in Figure 6.14 for the manufacturing pathway AKOQR discussed in Section 2 that has been applied to our efforts in managing technologies efforts at an enterprise scale. The MDM is laid out to show relationships within like elements (such as the process to process connections dependency structure matrix (DSM) in the red box, or the operand to operand connections DSM within the blue box or across unlike elements such as operand to initiative, as shown in the area labeled zone 1.

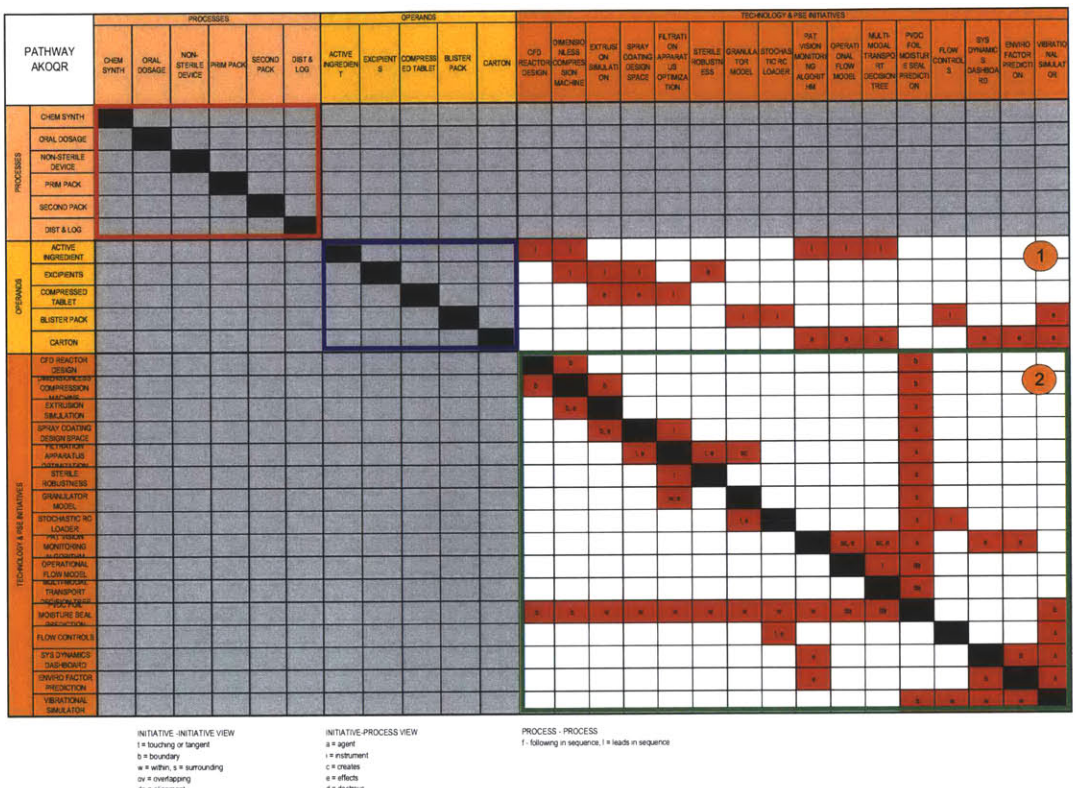


Figure 6.14: Multi-domain matrix (MDM) applied to manage interdependencies for technology and PSE initiatives.

Understanding the relationships between some of the most important potential efforts and the process or operands at the enterprise level is critical to help manage multi-year efforts and to foster the right knowledge sharing and hard connections required as internal and external resources execute on the portfolio of choices. The cross hairs within the matrix can represent the nature of the connection, e.g. "supporting", "connected" to or "integral". In this mock example, we see that the following projects are in the portfolio: CFD reactor design, dimensionless compression machine, extrusion simulation, spray coating design space, filtration, apparatus optimization, sterile robustness, granulator model, stochastic RC loader, PAT vision monitoring algorithm, operational flow model, multi-modal transport decision tree, monitoring algorithm, PVDC foil moisture seal prediction, flow controls, sys dynamics dashboard, enviro factor prediction, and vibration simulator. First and foremost, the importance of these PSE initiatives and their ability to address multiple needs at the global operational level would not be seen if were not for the roadmapping effort. The MDM analysis brings to light for example that the PAT vision monitoring project as creating datasets that are needed for the system dynamics dashboard or the enviro factor prediction model. These interconnections can then me mapped to intended resource connections through a process called organizational network analysis where people resources are mapped with their current structured technical and data sharing relationships (Cross et al, 2009). This leads to being able to visualize the resource connections between technical resources working on various programs and drive management of needed connections. An actual mapping of technical resource connections working in on the pathway AKOQR is shown in Figure 6.15.

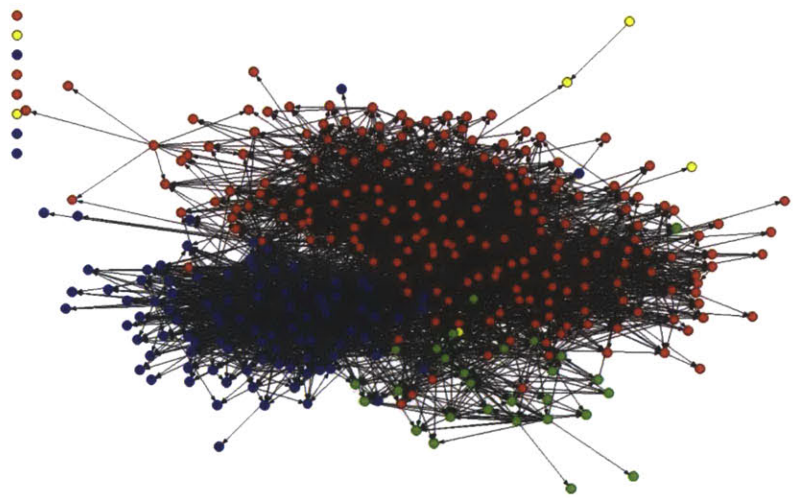


Figure 6.15: Organizational network analysis of connections between technical resources working on technology initiatives

The ability to impact human health and global sustainability requires enterprise transformation at size scales of global operations and time scales that traverse multi-year planning cycles. The Company implement this socio-technical system that has been pressure tested for one strategic planning cycle in our enterprise that combines technology roadmapping, portfolio management, multi-domain matrix and network analysis to methodical management of technology initiatives in an integrated and interdependent way.

The results of this initiative even in its early inception has been phenomenal from the standpoint of the KPIs listed both in terms of ability to impact and the actual demonstrated impact in programs underway already.

Given this account, we are able to now assess which of these conditions were and are present for this initiative and look at the how they each were either addressed or not addressed by the composite definitions in Section 4. This analysis is shown below in Table 6.1. In Section 5 we analyzed the greatest engineering achievements and compared the necessity of each of the 11 conditions we defined from the management science and change management literature. But in these, we were only able to segment the 20 achievements into cohorts of varying challenge level and empirically show that the greater the challenge level the more of the conditions are needed. However, the premise in the beginning are the intended results of the endeavors are indeed achieved, that is none of the endeavors ended in failure or delivered sub-standard results when viewed through the lens of history.

Condition Number	Condition Name	Present or Absent	Quality of Condition	Details
1	Burning platform and compelling destination	Present	A	The Company has made a strategic shift to expand to new patients and solve radically new healthcare problems, the status quo will not do and the ability to help billions of people is a compelling destination.
2	Single visionary who creates and evangelizes system-level design	Present	A	The visionary is present and through action taking on an increasing legitimacy role (Chief Technology Officer) for the Company.
3	Understands and balances technical and moral implications	Present	A	This is clear as the choices needing to be made have nuanced implications and need to be balanced carefully so that the greatest good can be maximized.
4	Six to nine key players	Present	A	A Technology Framework Team was put in consisting of 9 critical players who provide thought leadership and planning, this structure was repeated at two levels.
5	Relationship with the world is like a campaign or movement	Present	B	While multiple communications and communications have been conducted with extremely creative approaches, there does need to be an improved
6	Abandon false paths, maintain true north	Present	C	True north, the good of the patient, is established well. However, mental models prevent easy abandonment of a siloed way of working.
7	Intrinsically motivated brilliant or dedicated resources with adequate resource rate	Present	C	The intrinsic motivation is present but normal operational distractions and a very short time ramp prevents the optimal resourcing rate and learning curve.
8	Deploying prioritized, globalized resources while aggregating, synthesizing local innovation	Present	A	Through the technical inventories, which are truly a bottoms up and top down mechanism, the local ideas and innovations are aggregated, but roadmaps allow for deployment across.
9	Ideas good or bad get transmitted without variation	Present	A	Excellent propagation of concepts have occurred mainly due to the ability to document in very visual ways the thought process. Semetic transmission is engineered through pathways analysis.
10	Visualization of information, interdependencies, status, monitoring	Present	A	All visualization options from network diagrams, dashboards, DSMs, and roadmaps, have been employed and are providing value in processing and synthesizing a lot of complex information.
11	Segregation of decisions and actions by time cycles	Present	A	Establishing horizons for technology and even segregated strategy vs. tactical execution at three levels, this is working fairly well.

Table 6.1: An assessment of the conditions present for Technology Transformation studied at close range Company.

It feels almost obvious to say, but in our construct, the NAE's list of 20 greatest achievements are just that, they are great achievements and thus they don't look at the cohort of large socio-technical endeavors ending in failure. In order to do this what could we hypothesize would happen? Here are a couple of things to think about and expect:

> *The higher the challenge level the harder it is to achieve the results the endeavor is trying to achieve and vice versa.*
>
> *The more of the conditions present, the greater the chance of achieving the results the endeavor is trying to achieve and vice versa.*
>
> *The more effectively the conditions are met, the greater the chance of achieving the results desired and vice versa.*

And thus…

When the challenge level is high, the more conditions are met, the greater the success probability, thus the greater the results delivered.

We are proposing a simple grade point average (GPA) scheme in Table 6.1 using the 5.0 GPA scheme used at the Massachusetts Institute of Technology. Here are the associated grades:

A = 5.0
B = 4.0
C = 3.0
D = 2.0
F = 0.0 (in our case the absence of a condition)

Given this, we can define the "probability of success GPA" of this massive socio-technical system design, implementation and realization is actually calculated to be 4.54/5.0 from Table 6.1. While all the conditions were/are present, some are not at the state of optimality one would expect. However, as was the central thesis of the previous section, all the conditions exist, the critical one's are present and the since this is not the most challenging endeavor, success can be achieved as long as all the factors are present even if they are not at the full level. Using the same GPA scheme we can also give a GPA to the observed results, by looking at scorecards of the KPIs. For this particular endeavor, the Results GPA is 5.0. We can construct a semi-quantitative statement here about this endeavor.

For an endeavor of challenge level 5.04 that was actively managed to get a probability of success GPA of 4.54, we were able to achieve a results GPA of 5.0

We will title the Technology Roadmapping endeavor as "Endeavor 2011". To get some empirical evidence above, let us also examine the attributes of four other initiatives at the Company from 2003 - 2011, which had varying results GPAs and varying probability of success GPAs of the formulated 11 conditions. These projects are:

Endeavor 2005: Implementation of a speed maximized product development paradigm.

Endeavor 2007: A cross-company initiative to move to a more business unit structure, model and decision making.

Endeavor 2009: Replicating and modifying Endeavor 2005 for a different part of the business.

Endeavor 2010: Bringing three completely diverse legal entities together in a merger and integrating the companies under one whole.

The mapping of these endeavors to the challenge levels is shown below in Figure 6.16.

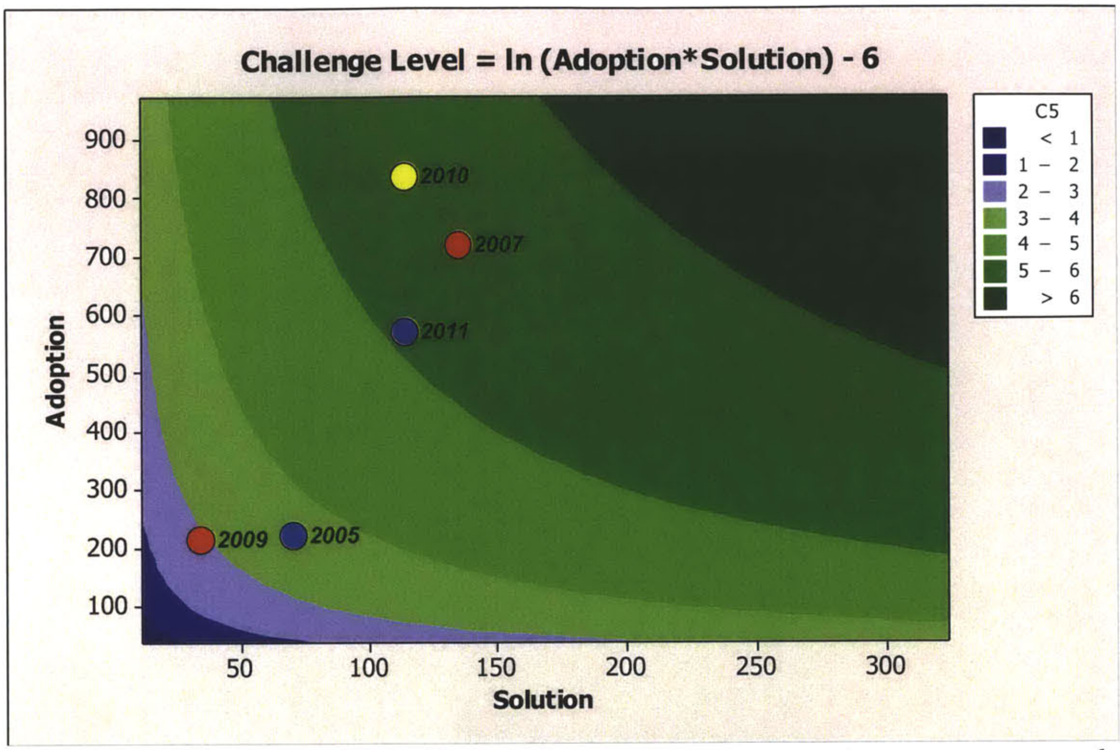


Figure 6.16: Mapping of the five transformational endeavors at the Company mapped against in the challenge levels. Red indicates a low results GPA, Yellow indicates a medium results GPA and blue indicates a high results GPA.

It is interesting to note that there are two cohorts in the challenge space of Figure 6.16. The programs 2007, 2010 and 2011 of greater challenge level (the ones in the challenge level 5-6 zone) and the programs 2009 and 2005 of lesser challenge level (that are in the challenge level zones 1-3). The colors represent the results GPA of the effort, where a red indicates low ultimate end results, a yellow indicates an average results GPA and the blue indicates excellent performance. So by comparing 2010, 2007 and 2011, we can test plot the POS GPA and the results GPA, and do the same for 2009 and 2005. We should find that for those in the challenge zone, the existence of the 11 conditions with greater prevalence (that is meeting the conditions of necessity and optimality). This plot is shown in Figure 6.17. If we examine the two cohorts, a couple of things become very clear. In the high challenge cohort in the red circle, the probability of success POS is correlated to the ultimate results. Put simply, the more of the 11 conditions to greater extent, the higher the ultimate results. The same is true for the low challenge cohort (with the blue arrows). Here however (at least for an N of 2) the effect is even more dramatic. And increase of POS GPA from 1.54 to 3.81 results in a jump in results GPA from a 0 to a 5.

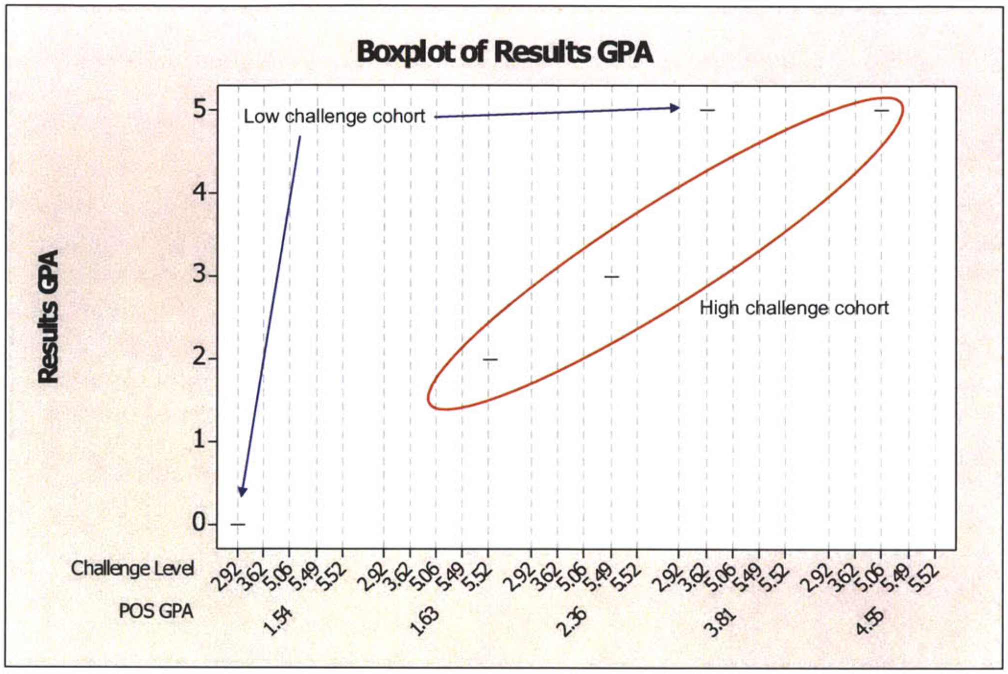


Figure 6.17: Examination of low challenge and high challenge cohorts and where individual endeavors exist on the results vs. conditions GPA.

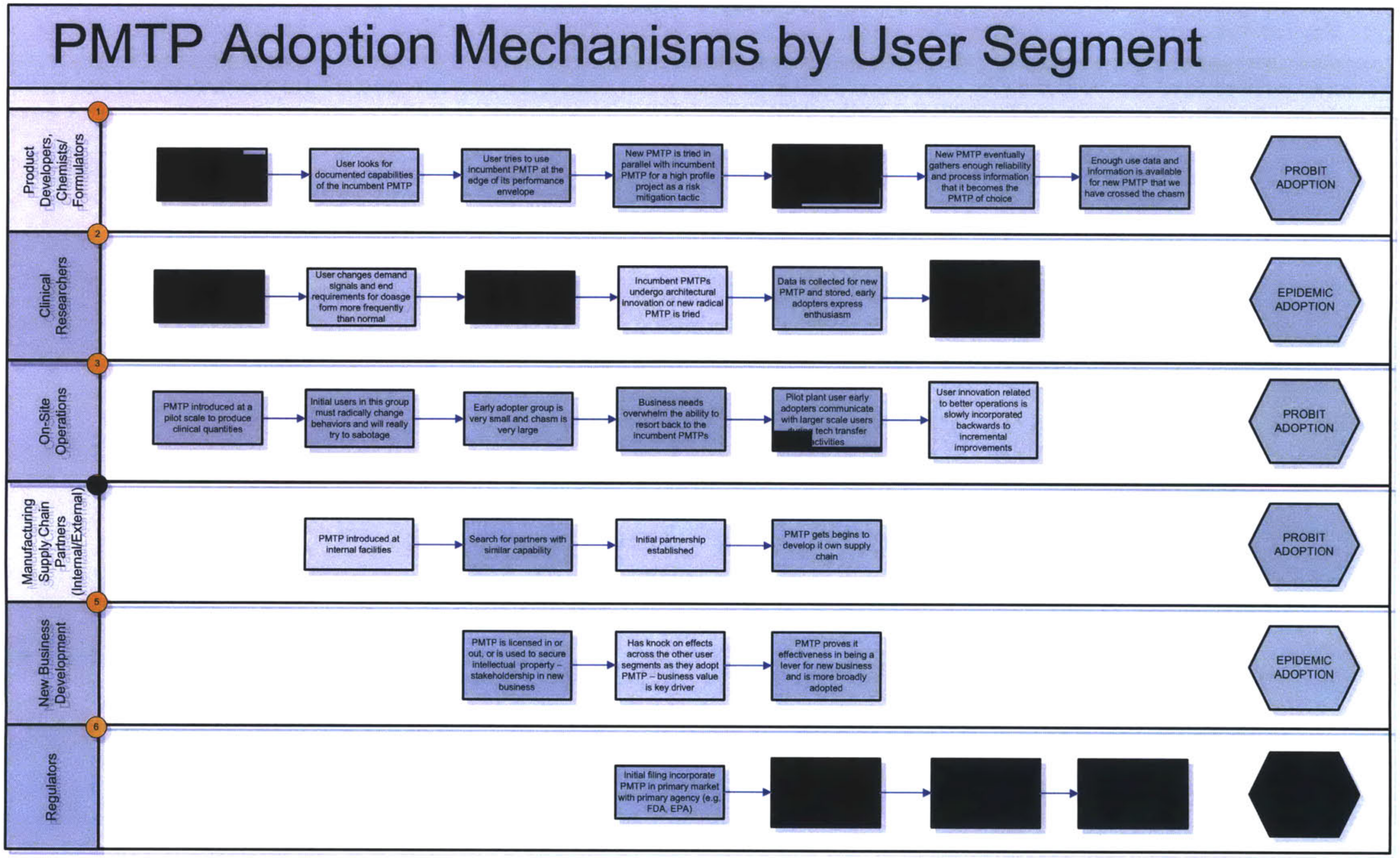
The regression analysis was conducted for the Results GPA using the challenge level and POS GPA as predictors. This is shown below. This yielded an R-squared of 90.1% which is viewed as fairly decent for such a small sample size and this type of semi-quantitative analysis.

Regression Analysis: Results GPA versus Challenge Level, POS GPA

```
The regression equation is
Results GPA = - 2.91 + 0.434 Challenge Level + 1.42 POS GPA


Predictor           Coef  SE Coef      T      P
Constant          -2.911    2.040  -1.43  0.290
Challenge Level   0.4343   0.4004   1.08  0.391
POS GPA           1.4207   0.3525   4.03  0.056


S = 0.945380   R-Sq = 90.1%   R-Sq(adj) = 80.1%


Analysis of Variance

Source          DF       SS      MS     F      P
Regression       2  16.2125  8.1063  9.07  0.099
Residual Error   2   1.7875  0.8937
Total            4  18.0000


Source           DF   Seq SS
Challenge Level   1   1.6933
POS GPA           1  14.5193
```

The deep analysis of Endeavor 2011 provides a great example of a high challenge level endeavor with success and the optimal presence of the 11 conditions. It was well worth the detailed analysis and the direct multi-year experiment (starting in 2009) to validate that purposeful engineering of the 11 conditions into the system increases the probability of success. We will find in the final section of this paper that Endeavor 2011 not only provides a great case study, but some of the internal content of the initiative itself is precisely what will be needed to solve the greatest human challenges identified in Section 1. We will explore how a Leader-Architect must build a socio-technical system centered around socio-technical roadmaps managed at a global scale. This will be presented as an organizational model, the elements of which are depicted in Section 5 and Figure 5.19 that can currently produced the description shown for the new paradigm of mission-oriented projects defined by Freeman and Soete in Table 5.5.

Additionally, the direct case studies within the Company allowed for the combination of three important semi-quantitative analytical tools in our study of challenging human endeavors. Figure 6.17 shows that the correlation between a value called the Probability of Success GPA and the Results GPA increases as the challenge level increases. Put simply, the optimality of each condition becomes more and more important in achieving results the more challenging an endeavor becomes. While a fairly straightforward and intuitive outcome, the value comes in the ability in the future to analyze a priori the probability of success of large endeavors on this simple analytical construct and to also a priori engineer success into large human endeavors through success analysis of the POS GPA. To test the validity of this beyond the close-range study done in this section, we apply this concept to a much larger global database of what are known as mega-projects. (Flyvbjerg, 2003). This rigor level 1 analysis is presented in Appendix B.


PMTP Adoption Mechanisms by User Segment
1
Product Developers, Chemists/ Formulators
[redacted]
User looks for documented capabilities of the incumbent PMTP
User tries to use incumbent PMTP at the edge of its performance envelope
New PMTP is tried in parallel with incumbent PMTP for a high profile project as a risk mitigation tactic
[redacted]
New PMTP eventually gathers enough reliability and process information that it becomes the PMTP of choice
Enough use data and information is available for new PMTP that we have crossed the chasm
PROBIT ADOPTION
2
Clinical Researchers
[redacted]
User changes demand signals and end requirements for doasge form more frequently than normal
[redacted]
Incumbent PMTPs undergo architectural innovation or new radical PMTP is tried
Data is collected for new PMTP and stored, early adopters express enthusiasm
[redacted]
EPIDEMIC ADOPTION
3
On-Site Operations
PMTP introduced at a pilot scale to produce clinical quantities
Initial users in this group must radically change behaviors and will really try to sabotage
Early adopter group is very small and chasm is very large
Business needs overwhelm the ability to resort back to the incumbent PMTPs
Pilot plant user early adopters communicate with larger scale users [redacted] tech transfer [redacted]ctivities
User innovation related to better operations is slowly incorporated backwards to incremental improvements
PROBIT ADOPTION
Manufacturing Supply Chain Partners (Internal/External)
PMTP introduced at internal facilities
Search for partners with similar capability
Initial partnership established
PMTP gets begins to develop it own supply chain
PROBIT ADOPTION
5
New Business Development
PMTP is licensed in or out, or is used to secure intellectual property – stakeholdership in new business
Has knock on effects across the other user segments as they adopt PMTP – business value is key driver
PMTP proves it effectiveness in being a lever for new business and is more broadly adopted
EPIDEMIC ADOPTION
6
Regulators
Initial filing incorporate PMTP in primary market with primary agency (e.g. FDA, EPA)
[redacted]
[redacted]

SECTION 7: WHAT IS THE SCIENTIFIC BASIS FOR THE NECESSARY CONDITIONS?

We now present a theoretical construction from first principles of evolutionary biology, cognitive science, neuroscience, psychology, and various other social sciences to present the causal reasons why we feel that the above construction is a viable means of assessing the potential success of challenging human endeavors and why these conditions are indeed the conditions. We feel that the assessment method truly embodies within it some of the fundamental learning from the last 40 to 50 years in a variety of different disciplines ranging from ecology and mathematics to management science and marketing. When we look at the most complex socio-technical undertakings, we are operating in an environment that is looking at enacting change, both within the community that is designing the change and also with the large global populations that will need to change on their own. We do this simultaneously as has been previously discussed. Thus at the center of it all is the fundamental unit of change and the target of our efforts, which is the individual human being. Our description of the first principles must end at this fundamental unit level of the person. What are the drivers of change and how do those change dynamics work within an individual? The understanding of the individual assessment will be built of the explanation of the dynamics we see in generalizes larger populations and take into account factors such as statistical distributions and network effects as factors that become more important in driving propagation of change across many people. Our first job must be to look at bulk behavior or masses of populations adopting change.

The dynamics of change and adoption of innovations across large populations has been studied in the most structured manner by Rogers (1968), where he was able to demonstrate the adoption of technical innovations in agricultural societies follow a Gaussian distribution or bell curve. This most famous bell curve is shown in Figure 7.1 below.

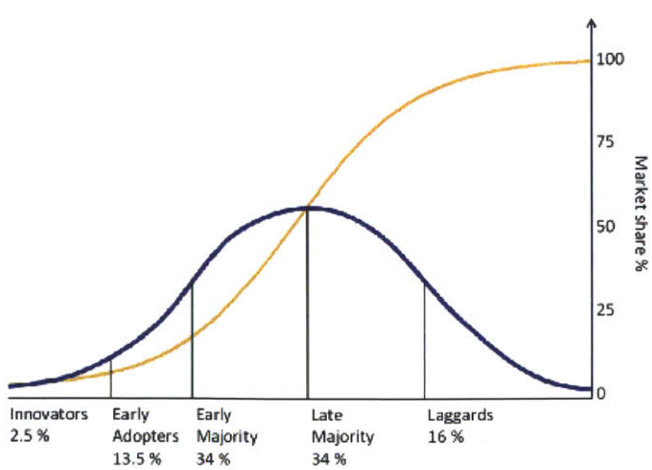


Figure 7.1: Rogers's diffusion of innovations curve

This well studied phenomenon reflects the fact that when the new innovation comes into a population there's an early set of individuals known as the innovators who are responsible for the early creation and design of the innovation and its commercialization into realistic and practical use. Next up are the early adopters who are able to use this innovation for reaping some form of benefit and then the rest follow with the early majority, late majority and the laggards. Over the last 40 years as we have studied the diffusion of socio-technical innovations across myriads of populations this distribution has remained true, even though the skewness were the shape has varied depending on the context or the circumstance or on physical or network barriers and enablers. Most of these studies have been conducted post de facto, accounting for and looking retrospectively at innovations that have already made their way through populations. There's been another avenue of study that is looked at success factors that account for the peak of the sigmoidal curve we see in the diagram showing the maximum market share possible. In these studies, we often find that the innovations don't make their way past the innovator or early adopter phases and thus the overall true potential of the technology becomes truncated in terms of share and in terms of the overall time present for the adoption to occur. This phenomenon has been termed "the chasm".

In his work, Geoffrey Moore (2002) has shown that the distribution shown by Rogers doesn't follow the neatly connected bell curve that the representation may suggest. Rather, if one were to take account in the x-axis for time one might see that there is a gap between the innovator and early adopter population and the early late and laggard populations. This gap in time between the early adopters and the majority has been referred to Moore as the chasm. In his studies of socio-technical systems and innovations Moore considers this the central problem for all new endeavors. And thus the adoption curve shown by Rogers above would better be represented by the chasm picture shown in Figure 7.2.

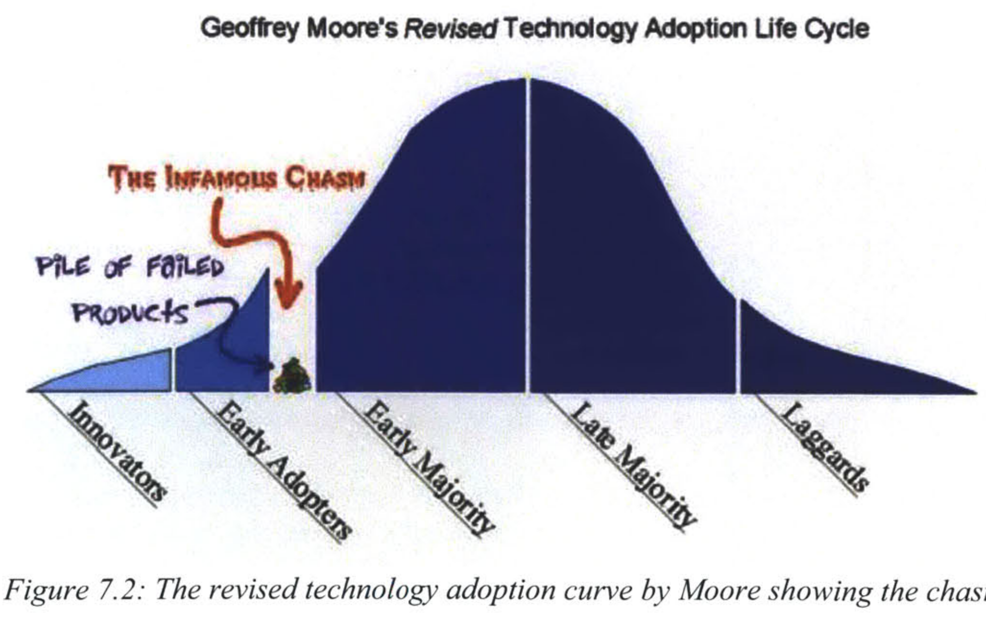


Figure 7.2: The revised technology adoption curve by Moore showing the chasm

What is incredibly important to note in this picture is the stylized depiction of the pile of failed products at the bottom of the chasm. What this indicates is that many efforts that start with innovators and early adopters actually fail and thus the whole distribution that could have been is actually represented an truncated and the smaller part of the distribution where the early, late majorities and laggards all become a part of the "early adopter" population and the lifecycle and true maturity of the technical system is prematurely ended. Empirical studies have shown that this failure rate is on the order of 10 times the success rate (Thomke & von Hippel, 2002) or 80 to 85% of all technology efforts (Moore, 2002). So what differentiates those socio-technical systems that are able to cross the chasm and those that do not?

There have been several approaches to study the factors and mechanisms that occur, resulting in socio-technical system adoption across varied human populations. They can be categorized into three primary archetypes. The first is an anecdotal or case study means which is been popularized by the author Malcolm Gladwell in his book the Tipping Point (Gladwell, 2002). In this entertaining formulation Gladwell follows the adoption of such consumer goods as Hush Puppies and other cultural phenomenon and how they have become popularized across large populations starting from very small innovator populations. Gladwell and as his journey by concluding that there is a critical mass of individuals that are influential in the adoption of any thing, be it a technology or an idea. Once this critical masses attained and those individuals are well networks, there is a natural "tipping point" where the larger system takes on the dynamic where the innovation or idea spread across large populations. Some of the characteristics of the individuals prior to the tipping point determines the ultimate success of the idea across large populations of people. He identifies three critical roles in architecting a tipping point and these are shown in the stylized network graph in Figure 7.3.

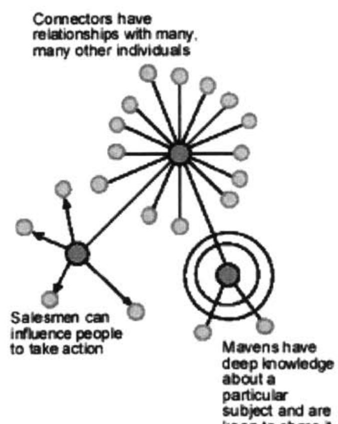


Figure 7.3: Three critical roles in creating a tipping point as coined by Gladwell

In this there are the influential mavens who have deep knowledge about a particular subject area and are keen to share it. They provide the data and deep understanding required to make people believe in an analytical and data-driven manner about the value of the change. They're the intellectual 'salespeople' who can influence people to take action, but in a more emotional way. These individuals are critical and helping people to create a visceral picture of a better future when the innovation is adopted. Lastly it is the connector who is the most important part of creating a tipping point. They are well-networked individuals who have access to both salespeople and mavens and can influence a wide variety of people through their relationships to adopt the change. This fits very nicely with the formulation given by Moore and the guidance that he gives around the circumstances and the situation that must be acknowledged when trying to drive a change across the chasm. Gladwell and Moore both recognize the fact that markets are not defined by geographics or by economic status or by job role as much as they are defined by the sets of individuals whom we reference and whose advice we trust in making our own decisions and choices. From a marketing science perspective, markets become groups of cross-referential individuals who would allow themselves to be influenced by the choices of their peers in the same group. Thus, in the traditional sense, Italy would not be a market, but a collection of much smaller markets, which span geographically, economically, occupationally and socially. The idea of a market is much more fluid than we have may have thought of in the past.

Since the structure of networks is important in the propagation of ideas, be they during the design or the adoption 'push' phase, it is important that we understand them. General laws about behaviors of networks in complex systems are being developed at the bleeding edge of systems study. We will lay down the foundation for a static network structure and then overlay the elements of dynamic network structures as this understanding will be so important to the causal explanations of the 11 necessary conditions we have postulated and studied thus far.

The study of networks transcend the human-to-human networks we are speaking of here, and expand to cover items such as the brain, the Internet, and basic biology. So as we try to contemplate the difference between nodes in a network, for our purposes a person in social network, what we are trying to influence is the emergent properties of the collection of nodes. In the case of design we wish to influence the behavior of the designers and in the case of adoption, we wish to influence the bulk properties of all the nodes. But action must occur at the individual nodal level. Any network is a collection of nodes (or vertices) and links among nodes (which are also referred to as ties or edges). Ties can be directed or undirected or carry weights or have no weights. Simple examples are nodes of people connected in a social network or community with ties that are relationships. Genetics is merely the nodes of genes tied through regulatory proteins and brains are neurons with synaptic ties (Mitchell, 2006).

Network science has laid out three very important properties of networks, they are:

> *The Degree of a node is the number of neighbors (connections) that a node has.*
>
> *Degree Distribution is the probability distribution of these degrees over the entire network.*

The clustering coefficient of a network is the average probability that two neighbors of a given node are also neighbors of each other.

Average path length is the average number of ties needed to connect one node to another in the network.

Mitchell, (Mitchell, 2006) has done a nice job of characterizing the types of networks studied extensively to date and how these properties can be used to identify them. They are listed in Table 7.1.

Table 7.1: Types of networks as simply defined by Mitchell (Mitchell, 2006)

Network Model	Degree Dist	Clustering Coeff	Average Path Length
Regular	Constant	High	High
Random	Poisson	Low	Low
Watts-Strogatz small world (low, nonzero *p*)	Depends on *p*	High	Low
Barabasi-Albert scale-free	Power Law	High	Low
Empirical results on real world networks	Power Law	High	Low

The most interesting phenomenon here is the similarities that real world networks have to the things called scale-free Barabasi-Albert networks. This means that degree distribution found empirically is described nicely by a power law:

$$P(k) \approx k^{-\gamma} \quad \text{(X)}$$

The probability that the k-th position has a certain degree distribution is represented by k raised to some real number power γ for which γ was found to be empirically between 2 and 3 for things such as electrical power grids, the Internet, networks of airline city connections, scientific collaboration networks, metabolic networks in biological organisms, protein networks in yeast (Barabasi, 2002). This is explained by the observation that preferential connections are made to nodes that already have greater degrees. So what is the most important characteristic in these network structures as we view propagation of change and are they the same roles that Gladwell purports are important in the diffusion of ideas and the dissemination of information amongst social networks?

Guimera and Amaral (Guimera et al, 2006) studied several structural roles in a network. They are:

Role Type 1: Nodes with many connections within a cluster (called hubs of modules)
Role Type 2: Nodes with only links inside a cluster (called ultra-peripheral nodes)
Role Type 3: Nodes with most of their links in a cluster (called peripheral nodes)
Role Type 4: Nodes with many links to other clusters (called non-hub nodes)

Roles Type 5: Nodes are homogenously distributed among all clusters (called non-hub kinless nodes

In studying these 5 roles in a network structure, the that end up being of most interest are the Role Type 1, a blend of 1 and 4 and number 5. From network to network, it is the Blended 1+4 (called connectors in Gladwell and Guimera works) that is most preserved in its structural importance. This provides the essential clue that the connections between highly clustered modules are extremely important and allow for the small world and scale-free effects of real entities like organizations etc.

We're continuing the study of networks now into the dynamics. Thus far, the attributes above have allowed the characterization of static observations, but much work has been done to characterize dynamic processing of information in a network through simple simulations called cellular automata. Put simply, can we, based on structure and the interaction rules, describe and predict how a particular network will evolve and what outputs it will yield. Cellular automata models are helpful as these are essentially spatially extended, decentralized non-linear systems that despite simple interaction rules can generate emergent properties that are hard to predict. However, the study of cellular automata has yielded some important principles of dynamics of networks. Scale-free networks are more evolvable than random networks for a task requiring the network to display some time-based behavior. Going back to Condition #11, this does explain how if each shell is a cluster based on the affinity of nodes over a particular time cycle, then the more randomly distributed the flows are (see Figure 4.13), the less efficient the behavior of maximizing Stock D becomes. This would then also translate into the populations through which propagation of the socio-technical system has to happen and the unfettered transmission must occur across multiple clusters requiring connectors and translators at every stage. One can argue that, in a fractal sense, the Leader-Architect of today is the connector of various clusters of technology from previous generations. There are some really dramatic implications of generational building of innovation and change through historical networks of technology which can be quite interesting and maybe the beginnings of a semantic. We will visit this notion as a "cultural aside" but it will not have much relevance for the direct causal architecture we are forming for explaining the necessity of the 11 conditions.

Pulling these threads together, it is important to note that tipping points happen in clusters due to a phenomenon called a phase transition. Just as in thermodynamics, networks go through phase transformations as shown in Figure 7.4.

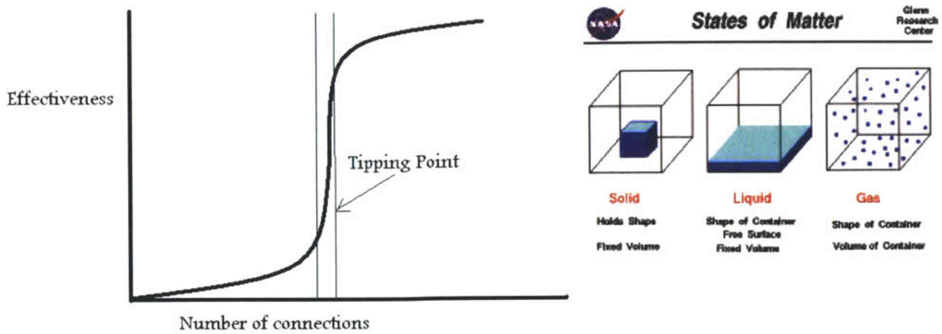


Figure 7.4: Phase transformation in networks and in matter.

When the number of ties equals or exceeds the number of nodes in a cluster, the cluster undergoes a phase transition. This is an important concept, as in a design effort, the collapse of the clusters within are important, but the propagation networks must also have purposeful phase transitions.

So what exactly in our kinds of networks is being shuttled around? We have identified two critical units of information being moved around in the networks we are studying. They are memes and the special subset of memes we called semes. It is worth describing semes a bit and the important role they play in technology. Think of the simple description of the a simple bit of technology, a canoe. Figure 7.5 shows the break down of the canoe in a familiar system architectural manner with physical form to process from operand through function to beneficiary.

FORM	INTERNAL PROCESS	OPERAND	INTERNAL FUNCTION	PRIMARY EXTERNAL VALUE FUNCTION & PATHWAY	PRIMARY BENIFICIARY
BOUYANT VEST	PROTECT	ROWER	HOLD ROWER	HOLD ROWER AND PROPEL ROWER ABOVE THE WATER	ROWER
PLANK	SUPPORT	ROWER			
HOLLOW BODY	CONTAIN	ROWER			
TAPERED BOTTOM	DISPLACE	WATER	MOVE THROUGH WATER		
PADDLES	CUT	WATER			
ROPE LATCHES	SECURE	ROPE	DOCK CANOE		

	Shows the principle value related operand and primary internal functions

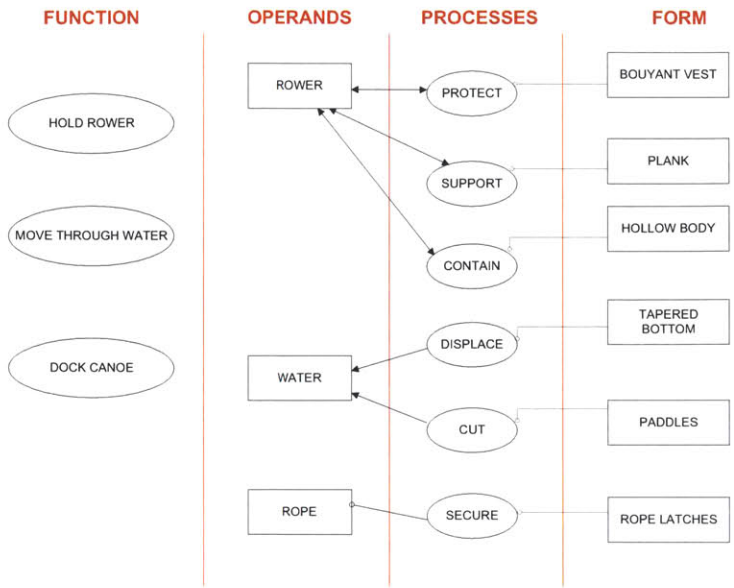


Figure 7.5: A simple system architecture for a canoe.

We can further imagine reducing a canoe in to simpler combinations of function-form down to very basic irreducible components, which we are calling semes. The combinations of these irreducible components in special ways would give rise to mechanisms of self-selection and functionality. The concept of semes is that as they are the fundamental selected unit of the socio-technical systems, that is combinations of physical and social technologies (Nelson, 2003). If we examine any evolutionary system it must contain certain fundamental components that must exist for the algorithms to work (Beinhocker, 2006). A classic example is of course what Darwin studied in the domain of biology, the algorithm needs an interactor or agent (nodes in our network model) which is the organism. It needs some scheme to replicate (for us it is the seme in a socio-technical system) such as DNA that encodes information and some scheme reader that unpacks it some way for use or processing. The scheme helps to build or create the fundamental building blocks in the case of biology these are proteins which are then selected by some fitness landscape because their fitness function. The replication mechanism for the schema can be many types, in the case of biology is reproduction. Variation of the schema is usually through random mutations that are selected or not selected by some fitness landscape. In the case of biology, these are genetic mutations that serve to afford some advantage, major or incremental, to the organism thus being selected by the success of that organism in an ecosystem.

The evolutionary algorithm is truly remarkable as the framework can be applied to so many socio-technical system domains as seen in Table 7.2. What is of chief interest to us at this time is the selection of memes and semes. In this there are two primary mechanisms or archetypes in the evolutionary algorithm. The first is the random mutation and selection through advantage in the ecosystem, which is a passive system based on chance. This is the Darwinian mechanism. Then there is the active or directed evolution which changes purposefully or in a directed manner the schema itself or the fitness function, and this is Lamarckian mechanism. It is a combination of Darwinian and Lamarckian mechanisms (passive and directed evolution) that are at play in the domains outlined in Table 7.2. We are particularly interested in memetic and semetic creation, combination and propagation in socio-technical systems. This brings us down to the individual node again. What are the dynamics of adoption at the node-to-node level?

Table 7.2: The evolutionary algorithm and examples

System Type	**Interactor/Agent Design Space**	**Replication Mechanism**	**Adaptation Mechanism**	**Schema**	**Schema Reader**	**Building Blocks**	**Fitness Function Landscape/ Environment**
Biology	*Organisms*	*Reproduction*	*Mutation (Random) Environmental Manipulation (Proactive)*	*DNA*	*Genes*	*Proteins*	*Ecosystem*
Economics	*Businesses*	*Amplify*	*Emergent (Random) Innovation (Proactive)*	*Knowledge Management - Business Plans - Modules*	*People*	*Social & Physicial Technologies*	*Market*
Computer Science	*Programs*	*Run*	*Mutation (Random) Combination (Proactive)*	*Code*	*Processor*	*Subroutines*	*Computational Results Space*
Political Science	*Civilizations*	*Expansion*	*Proactive Mutation*	*Rules of Law*	*Governments*	*Social Technologies*	*Society*
Traffic	*Traffic Jams-Flows*	*Education, Instruction*	*Emergent (Random) Innovation (Proactive)*	*Driving Norms*	*Drivers*	*Driving Tactics, Traffic System Settings/Design*	*Roads*
Language	*Words-Phrases-Slang*	*Written-Oral Repitition*	*Mutililation Misuse Neologisms*	*Language*	*People - Societies*	*Letters-Sounds-Words*	*Norms - Popular Culture*
Organizations	*Members*	*Adoption - Amplification*	*Emergent (Random) Innovation (Proactive)*	*Semes*	*Members*	*Social & Physicial Technologies*	*Organizational Culture*

Gladwell's notions, while anecdotal, underlie certain fundamental truths about propagation of ideas that can be proven via first principles—models around how ideas get propagated. This leads to the second archetype of adoption, which is a memetic one (or semetic one). Memes are self-reproducing mental information structures analogous to genes in biology, can be seen as the basis for an explanatory model of cultural and psychological behavior. Their properties and effects are evolutionarily conditioned and, when looked at on a bulk basis, it would seem that they are ultimately seeking to promote their own replication. To survive in a context the memes must meet certain conditions. Examples of memes are music, ideas, fashions, ways of creating artwork or building houses. Examples of semes, as introduced in a previous example, are the idea of lifting a physical object to increase potential energy and dropping it for conversion to kinetic energy. For our purposes, they represent the change in behaviors required to adopt a change for a new socio-technical solution. Semes propagate in the gene pool via a process which, in the broad sense, can be called imitation. If a connector hears a good idea or witnesses a maven with a special tool and it catches on , it can be said to propagate itself, spreading from brain to brain. Semes get selected and influenced by the larger socio-technical systems they sit in. The idea of a meme is so powerful because it readily takes advantage of the theory of natural selection and evolution that has been proven to be such a foundational concept of complex systems and advantage of Lamarckian and Darwinian mechanisms. For natural selection to occur, there are certain conditions that must be met. First, there must be active or passive variation, and in this case, there must be variation of different ideas, memes or semes. Heredity or replication: the elements have the capacity of creating copies or replicas of themselves. Differential "fitness": the number of copies of an element that are created in a given time varies, depending on the interaction between the features of that element (whatever it is that makes it different from other elements) and features of the environment in which it persists.

This is a quite general definition that is not limited to biology, and suggests that memes are subject to natural selection: they vary (due to "mutations" in transmission or mental storage, plus deliberate changes), they replicate (by definition) and have differing fitness. This leads to phenomena of competition, co-evolution, population dynamics and adaptation surprisingly similar to biology. There would thus be a set of shared memes or semes from the meme pool or seme pool (in analogy with the gene pool). At the core of all of this are the two selecting things that determine fitness. The first is the environment and for semes, it is often other physical systems, compatibility and the like. For the broader set of memes it is human. At the end of the day, it is either the direct human or the environment or ecosystem that the human has inadvertently created that sets the fitness landscape. This brings us to the next important question in our definition of these important scientific findings and principles.

So what is it at the individual human level that allows for the threshold to be crossed that we adopt of make a link on an individual basis? The most important empirical work that has been done to study how individuals view change has been from Daniel Kahneman (Kahenmen, 2011), the Nobel prize-winning economist. Put simply, his work has shown that humans have a threshold beyond which they're willing to change from their status quo. This threshold is empirically determined to be 2 to 3 times better than their current situation. The fact that this level of change and this magnitude is so high from the status quo indicates that human beings have a preference to stay in their current situation rather than moving to something different. The experiments that Kahneman has conducted has shown that this aversion to change translates into economic choices as well as social choices.

To illustrate this finding in a more concrete and tangible way we can take the example of two individuals in a thought experiment. Consider the first individual to be a prisoner locked away in some deep dark dungeon away from the world with barely the small amount of sustenance that he needs to survive on a day-to-day basis. This would be this individual's status quo or current state. Now let's say that the dungeon door has been opened, and a means to this person salvation is practically at hand. All the individual needs to do is get up and walk out the door and he will present himself with the opportunity for freedom away from his current condition. Applying the idea of a threshold to this case would mean that the individual is weighing out the option of staying in the dungeon or walking out the door to a salvation. The change is represented by the act of walking out the door. As the individual weighs the choices he is weighing the cost of the loss that he would feel in leaving his current condition added with the cost of the uncertainty that he would face in a world of freedom. In the mind of the individual, the future condition that he might find himself in is clearly on a magnitude basis 2 to 3 times better than his status quo of imprisonment. He is thus apt to make a change willingly and readily even at the cost of the loss or uncertainty that he will face in making that choice. What contributes to the clarity in this decision is the visual image that he can create for himself about the fact that the future condition will indeed be several times better than his current condition. He is able to envisage how good freedom will be in comparison to being imprisoned in the dungeon.

Let us now consider a second individual. This is a lady that is trapped within a deleterious romantic relationship. The man that she is with is often irresponsible, unforgiving, and not attentive to her feelings or her hopes and dreams. However, he does provide a sense of stability and familiarity, and has presented, on rare occasions, the ability to be tender and caring. She has often thought about leaving this individual and going out and seeking a different relationship. Breaking up with this man and putting herself out into the uncertain world of dating and seeking represents the future condition away from the status quo. In the threshold formulation presented by Kahneman, this future condition in the mind of this individual must clearly be 2 to 3 times better than her status quo in staying with the man. In this particular case, the cost-benefit analysis and truly representing and believing that the alternative to the status quo is indeed several times better is harder to do. The loss part of the equation is represented by giving up the few moments of tender, caring that she has encountered with this individual and the uncertainty part of the equation equates to the inability or the lack of success in finding a better man. We are also hampered in this choice by the level of imagination that this individual can put towards creating a vivid and better future description, where she herself believes that the future condition will be better, several times better. In this we will find that many a times this individual will choose to stay in a relationship that in absolute terms is not the best rather than facing the loss and the uncertainty because they do not cross that 2 to 3 times better threshold.

What is remarkable in this formulation is that this threshold is constant amongst all human beings. As a matter of fact it can be argued that this is a part of our basic cognitive programming that has been chosen over many generations of selective pressure because it is afforded our ancestors a survivability advantage over not having this threshold. If this threshold is truly axiomatic for all human beings, then the question arises why do some people move quicker to change than others?

In the study of cognitive evolutionary processes, it is shown that there are two aspects of change that have been programmed to be unfavorable to us from the Kahneman and other fundamental work.

> *An aversion of losing the past that is familiar (thus safer as cause and effect relationships are clear)*
>
> *A fear of an uncertain future (thus less safe as the cause and effect relationships are less clear).*

There is a premise in cognitive psychology that the we prefer the status quo as our brains have evolved to be Bayesian hypothesis testing machines. Thus the larger the database of status quo in which cause and effect relationships are known, the more likely the individual wants to stay there. This would have afforded those humans that had this feature an advantage, particularly if they set the threshold high enough to avoid unknown dangers. This is likely where the 2-3X threshold comes from. This also explains the observation of the existence of mental models (Senge, 2006). Mental models are explanations of an individual's thought processes that explain how things work in the real world. They are the schemes of cause and effect, built from years of Bayesian testing (starting perhaps in the fetal brain) that build these mental models. Mental models are about learning and from the standpoint of how they effect decision making in the real world. And as Kahneman has so effectively shown, our propensity is to validate existing mental models and ensure that our decision making stays consistent with the status quo unless the information feedback is so great that. This is depicted in Figure 7.6.

The evolutionary selection process has been selected for through Darwinian means and often reinforced through Lamarckian validation during life from parents and peers that there is actually a secondary phenomenon that is observed in behavioral economic and evolutionary psychology. That is the hard wiring of impact disproportionality. (Gilbert, 2006). This is the tendency for humans to overdo emotions. We tend to be too happy about good outcomes and too upset about bad outcomes. Again a bias towards the status quo likely built through evolution. Additionally, Kahneman also showed that we tend to have two systems in our brains, the experiencing self and the remembering self (Kahneman, 2011). The remembering self often has this same disposition towards over-doing the good in the past and over-lamenting the bad in the past. So the true task of the change agents in driving adoption of a new way to design a socio-technical system or propagate the change in behaviors required to make it successful then is all about crossing the 2-3X threshold and that is all about convincing individuals that the future condition is that many times better than the status quo.

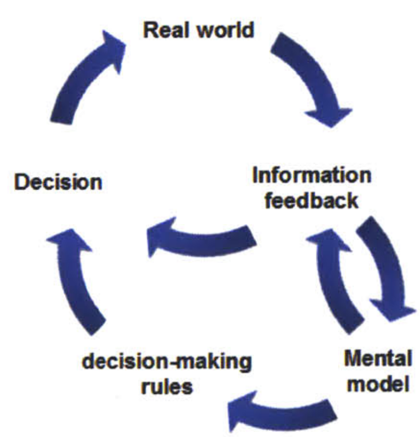


Figure 7.6: The depiction of mental models and the rules that govern decision making. (Sterman, 2000)

The existence of mental models to some extent explains another phenomenon frequently experienced in humans. This is the concept of functional fixedness (Davies, 2009). Functional fixedness is the cognitive bias in humans that limits an individual from seeing alternate uses to an object than it has been used in the past. Getting over functional fixedness, influencing mental models and crossing the 2-3X hurdle are the things that need to be done for a change to propagate. For this to happen, the compelling destination must be articulated and believed in away that individuals can truly internalize that the future condition indeed will be better. We will say that they need to create a story in their minds that they can seem themselves in.

This is where we can take advantage of other fundamental systems built into the neurology of every human being.

> *Mirror neurons: neurons in the brain that fire at two instances, when the animal is doing an action or when the animal is observing another animal doing the same action.*

The discovery of mirror neurons has caused quite a stir, and their functions in the human brain are still being determined. However, the arch of science is speculating several things about the reason for existence of these neurons. About a 100,000 years ago, the human species began to make great leaps and bounds and seme propagation and integration exploded. This was accompanied by a largening of the pre-frontal cortex along with what was hypothesized to be mirror neuronal explosion (Ramachandran, 2011). This allowed for learning to occur through emulation. It has been shown through experimentation that mirror neurons fire when observing others analogous to the person themselves having the experience. The optimal learning cohort utilizing the mirror neurons also coincidentally is in groups of 6-9 people which was likely the number of individuals in families or hunting packs. As hunting techniques moved to agricultural techniques the efficiency of the six-nine number continued.

Most remarkably in the study of mirror neurons is the observation that an amputee feels relief in his or her own phantom limb when observing someone else massaging their own hand and this effect is coupled with increased effects in the areas of the brain associated with mirror neurons.

Gazzola et al did some extensive work in looking or auditory mirror neurons and found the some startling imagery about the effects on a musician listening to another musician playing a musical piece. This is shown in Figure 7.7. The musician listening is actually experiencing firings in the areas that would control motor neurons to move the arms and fingers the same way as if he or she was actually playing the instrument themselves.

The speculation on the functionality of mirror neurons includes: understanding intentions, empathy, self awareness, language, automatic imitation, and motor mimicry. While there is much counter proposals around the importance of mirror neurons and the science is by no means complete, it is interesting to note that observations do point to some neurological reason for imitation and learning between humans. So why is this important to the sequence of scientific explanations of the 11 necessary conditions? It is the importance of emulation in driving changes in behavior that we speculate is vital to a major portion of the 11 conditions.

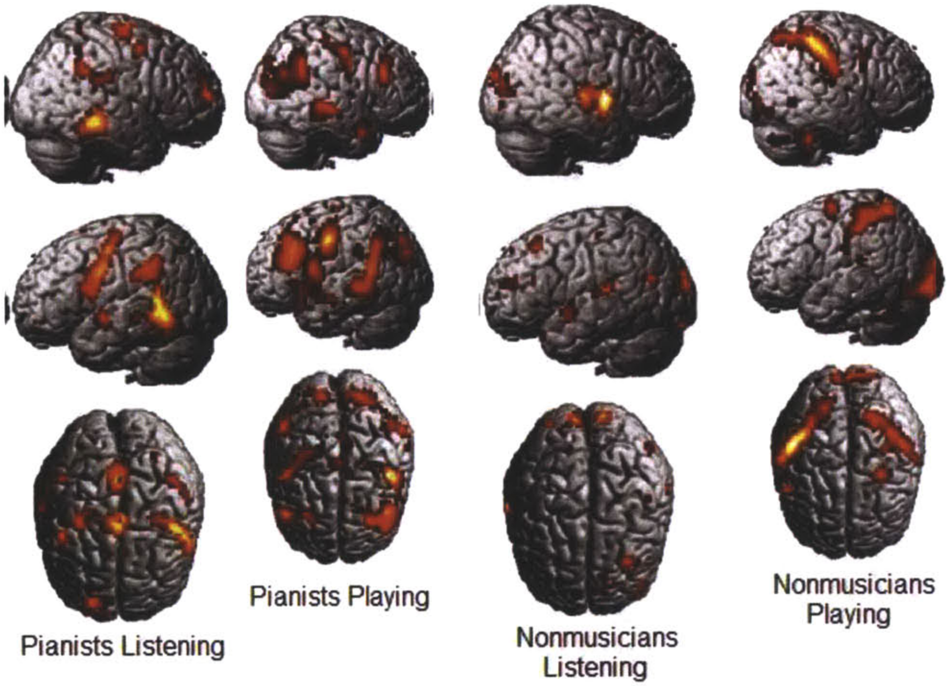


Figure 7.7: Gazzola et al study of auditory mirror neurons (Gazzola et al, 2006).

When individuals see other individuals they trust behaving in a certain manner, the hypothesis that learning happens, synthetic experiences are created in the mind and in some cases the behavior shifts through emulation. Taken at its most complex level, viewing others engaged in a different behavior than the status quo indeed through emulation and learning can help individuals cross that 2-3X threshold. It allows people to get over the start friction of actually beginning to change behaviors. Take a simple thought experiment. For an individual who has never seen benefits of utilizing a cell phone and has never even seen one, it becomes hard for them to imagine, but if some node in their social network begins to use it, and they can observe this utility.

Going back to the Leader-Architect concept, this individual is thus able to see and behave in accordance with what the change needs to be, either for the design forces or the future change agents driving the change across large populations. We can extend the theories of leadership according to Howard Gardner a renowned social scientist and professor of cognition and education at Harvard University to our concept of Leader-Architect. The Leader-Architect achieves their effectiveness through the stories they tell according to the Gardner theory of leadership. Leader-Architects are those that can affect the thoughts, feelings and behaviors of large groups through the effective communication of stories. In Gardner's view, leaders must have a central story or message that individuals and groups can readily identify with; they will agree on the story or message even years later. Leaders also embody their stories. They convey their stories by their example. In addition, Gardner says, "stories must in some way help audience members to think through who they are." And stories must do more than provide background. "They should help an audience frame future options." (Gardner, 1996).

It is the concept of emulation that is important. Not only does the Leader-Architect help create the 2-3X threshold by creating a visceral and vivid picture of the future that people can see themselves in, but the exercise the mirror neurons of others by embodying the change that he or she wants to see. It can be said that the Leader-Architect can do this, through a demonstration of the three appeals of Aristotle, Logos, Pathos and Ethos (Rampage et al, 1998). A Leader-Architect appeals to the individual's logic (Logos), their emotions (Pathos) and ultimately carry in their own being the set of experiences and weight from the stock of their own personal experiences (Ethos). It is the combination of these that make the Leader-Architect effective in activating mirror neurons, get over loss aversion and future shock.

The science behind the 11 conditions is becoming a bit clearer. There are three other building blocks that are required to complete the full causal chain. It was said earlier that while the Leader-Architect can drive certain change, they must make certain things "un-violatable", that is maintain true north as well as balance morality and technical issues. So the Leader-Architect must not violate some core parts of human morality.

> *Morality algorithms coded into the brain: a system hypothesized by cognitive biologists and neuroscientists that explain universal pillars of morality observed in humans and some higher mammals such as primates and dolphins.*

The pillars of morality are reciprocity and fairness and empathy and cooperation. The Leader-Architect uses these to bolster the story, underlying the strong tones of empathy and fairness that humans hold as bedrocks for any worthwhile endeavor.

The last framework helps to explain how humans can successfully traverse the journey from the current behaviors that represent the status quo to embodying the behaviors and skills congruent with the future condition. Here we look at the two remaining bits of science that explain how humans can traverse this shift moment by moment. The first is the concept of the flow state, described by psychologist Mihaly Csikszentmihalyi. The flow state was studied and found that a condition exists for humans whereby the work that they are engaged in being slightly above their skill level helps improvement and allows people to enter into a state of complete engagement. This engagement then allows the individual to keep ratcheting up their skills and performance. This also explains the mechanism of innovation as well, where the path to innovative leaps (or in our framework, directed evolution) are helped by each successive leap in the people capabilities towards some exploratory end goal (Csikszentmihalyi, 1996). The model is shown in Figure 7.8.

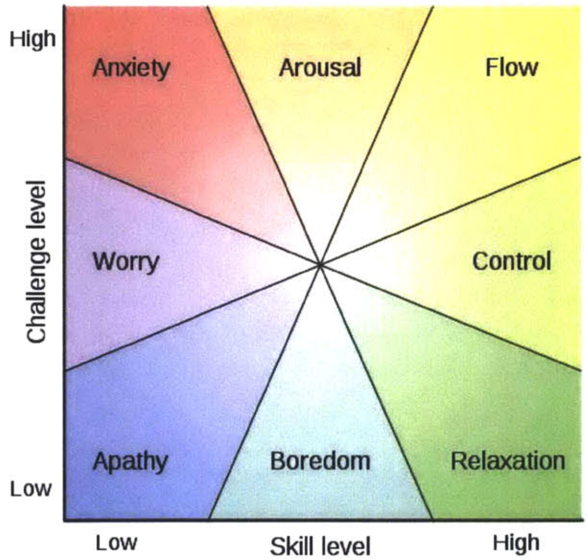


Figure 7.8: Flow state model described. (Csikszentmihalyi, 1990)

This can be expressed simply as a causal loop diagram that we have conceived shown in Figure 7.9. It is the job of the Leader-Architect and his or her core crew to delicately balance the reinforcing loops R1 of having had enough of an insurmountable challenge, to the balancing loop B2 of a "ho hum" situation where the challenge is too easy. Change is a control loop of getting a group of people to live in the flow state as the required performance needed to drive or adopt the change is created.

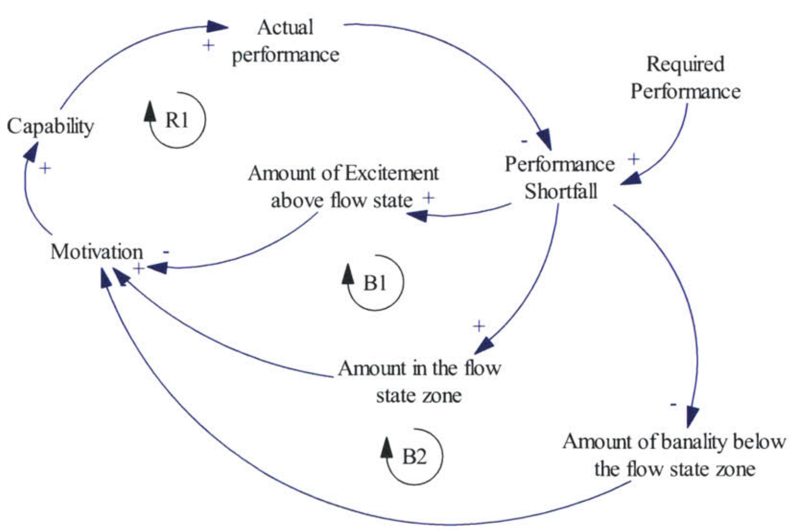


Figure 7.9: Simple causal loop diagram of the flow state.

Lastly, one can ask how is the Leader-Architect and his/her core crew of 6-9 individuals actually acquire the skills that they have to use logos, pathos and ethos and story telling to drive change? Here we turn to last bit of science and that is the much publicized

10,000 hours rule. While mirror neurons help with initial acquisition of skills, it is the living of the flow state loop in Figure 7.9 that grows the skills over time. Studies by Ericsson have shown empirically that world renowned experts in any area are created by 10,000 hours of continuous and repeated practice (Ericsson, 2006). While there is still much science yet to be done here, the 10,000 hours rule is seen clearly in many of the Leader-Architects we have spoken of before from Martin Luther King Jr. to Robert J. Oppenheimer. None of these individuals entered their initiatives with no experience. Rather the success came, the inflection point was achieved once they had fully traversed their own 10,000 hours, be it oration or civil liberties studies or nuclear physics and political maneuvering, the skill of being a Leader-Architect needs practice and repeated attempts at accomplishing hard things that are just a bit above the talent level of the Leader-Architect.

Now that we have explored all the latest integrated science from the natural and social sciences, it is time to revisit our synopsis of the 11 conditions from Section 3 and explain them with the scientific causes behind them. This is the following narrative:

> *The existence of a burning platform and a compelling destination creates the situation whereby we as humans are able to overcome loss aversion and uncertainty paralysis that makes us prefer the status quo over change due to the evolution of our brain structure. A single visionary leader-system architect is able to create and evangelize a system-level design across all beneficiaries by creating a compelling story of the future that people can see themselves in so viscerally that they are able to cross the 2-3X improvement threshold that is common to all humans. The leader/architect understands and balances the technical and moral implications by never defying the fundamental human moral foundations of empathy and compassion, reciprocity and fairness but using deep knowledge acquired through 10,000 hours of practice in their craft to make nuanced, pragmatic judgments. The leader-architect is able to seek counsel, support, convergent and divergent ideas from a core group of 6 to 9 key players and together, taking advantage of evolutionarily determined optimal human group sizes and brain accounting. He or she is able to model the behaviors required to build the socio-technical system in question by taking advantage of mirror neurons. This core group's relationship with the outside world is like a campaign or a movement through influence networks that take advantage of the small world effect of short path lengths and high degrees of clustering to enable phase transitions in networks whereby the number of ties is equal or greater than the number of nodes. The larger ecosystem in which the single visionary leader and the 6 to 9 core players sit allows them to abandon false paths on their journey from the burning platform to the compelling destination. They are enabled by intrinsically motivated and brilliant or extremely dedicated people resources with a sufficiently rich resource rate in the larger organizational system, which takes advantage of power law efficiencies in networks. This allows for the deployment of prioritized and globalized resources while at the same time enabling the aggregation and synthesis of local innovations. This is accomplished by having ideas good or bad be transmitted with minor variation, which necessitates the*

need for the creation of tools that allow for the visualization of information, interdependencies, status, and monitoring of ongoing progress so that memes and semes can be selected through Darwinian mechanisms and modified through Lamarckian mechanisms. This all results in a system-level segregation of decisions and actions by the appropriate time cycles in which these decisions and actions need to be made and taken which again enables the resources to achieve the proper flow state that they can handle for their skill level, in other words the not being too hard or too easy falling in the "Goldilocks Zone" of human achievement called the flow state.

Of course this linear narrative does not do justice to the true relationships between the latest in natural and social sciences and the 11 conditions defined in our study. Rather, each on of the conditions is bolstered by more than one of the scientific underpinnings we have established. We have represented the connections in Figure 7.10 between the fundamental scientific underpinnings (on the right) and the 11 conditions we derived from an inventory of all the most cited management theory on the topic (on the left).

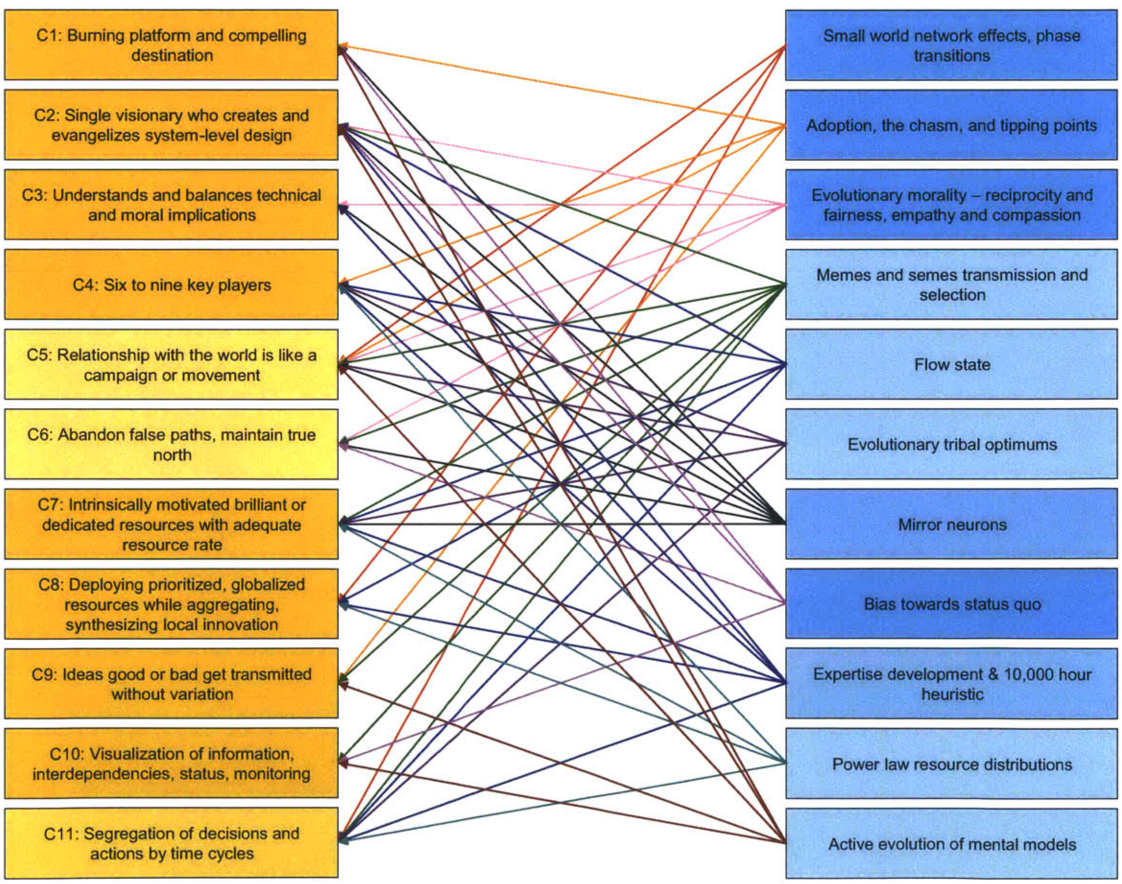


Figure 7.10: Connections between the necessary conditions defined and recent scientific foundations

It can be easily seen that each condition is not explained by just one underlying scientific theory, but by many. We feel that this solid connection to fundamental science in this area coupled with the resiliency of the empirical observations and the exhaustive correlation to almost all management theory shows the incredible power of this framework. The 11 conditions not only enjoy solid empirical validity but can be explained by contemporary natural and behavioral science.

SECTION 8: WHAT IS AN OPTIMAL SCHEME FOR SOLVING OUR CONTEMPORARY HUMAN CHALLENGES?

In previous sections, we have been successful thus far in developing a set of necessary conditions for success in the most challenging human endeavors. The first step was in to define our concept of challenge and develop a semi-quantitative approach to defining challenge level by looking at the dimensions of difficulty of design of the solution and the difficulty of the propagation of the solution across the populations that it needs to influence to make a positive impact. The conditions themselves were defined through an exhaustive meta-study of the most relevant literature on the topic utilizing a taxonomical scheme that allowed for grouping of multiple ideas underneath common ideas. This process yielded 11 primary conditions that appear and are validated across some a diverse and expansive set of recorded and cited management theories. We went further to test the premise that all these conditions are necessary on the most challenging endeavors by testing their absence or presence in some of the most crucial events in the stories of the 20 greatest engineering achievements of the 20th century. We also tested them in a rougher sense against many of the mega-projects carried out in the past 100+ years or are being carried by humanity today. This provided confidence in the concept of necessity.

We went on to test the optimality question of each of these conditions by inventing a simple scale for mapping the level of each condition (beyond just mere presence of absence) and the level of results or outcomes achieved by endeavors within a specific multinational company with global reach and particular mission related to global human health. This helped us realize that the degree to which each condition is achieved becomes important the more challenging the initiative becomes. We also took time to delve into great detail on specific, multifaceted endeavor carried out at this company in which the 11 conditions were purposefully coded and tested for the results and success. By studying in great detail a specific live case (conducted over the last 3 years); we were able to show the specific choices that can be made with knowledge of the 11 conditions to increase the probability of success of a highly complex human endeavor.

With these detailed empirical and case analyses in hand, our last section covered a theoretical construction from first principles of evolutionary biology, cognitive science, neuroscience, psychology, and various other social sciences to present the causal reasons why we these 11 conditions should matter, and demonstrated that the fundamental science bolsters the premise of the existence of these conditions as the most important, proved their necessity and also reasoned why there are optimal points for their application and existence within an endeavor.

With this framework and evidence in hand, we are ready to go back to the original problem presented in Section 1, and that is assessing the current approaches to the current big four issues of health, poverty, environment and peace. The first step is to clearly define the problem and understand the dynamics of the situation. The initial set of dynamics at the highest level was delivered in a classic controversial study of the human future by Meadows and company. It had a non-technical presentation of structure, assumptions, and results of what was called the WORLD3 model using system dynamics, a new methodology at the time developed by Jay Forrester. That study presented the fact that global policies were unsustainable and showed how alternate policies could stabilize population at a high standard of living. (Meadows et al, 1972). Jay Forrester, the father of system dynamics added to this with a simple global model on which a future work called *Limits to Growth* would be based. The model was extremely simple and able to be shared with a wider audience but was extremely powerful in describing the fundamental forces at play (Forrester, 1973). This model was formulated by Morrison for analysis and this diagram is shown in Figure 8.1 (Morrison, 2010).

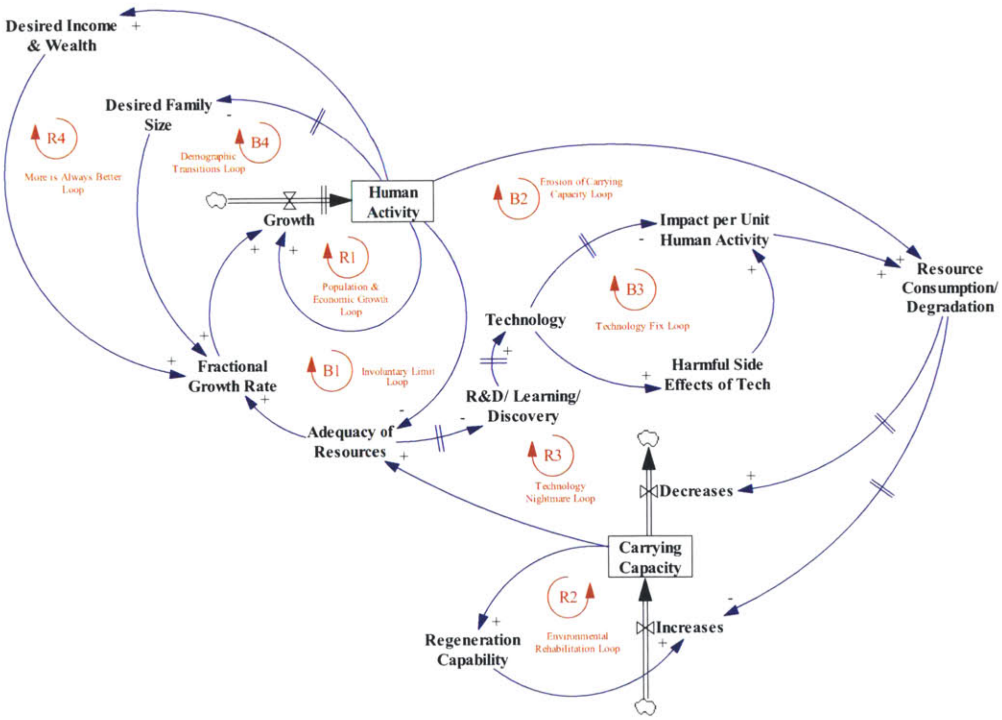


Figure 8.1: Forrester model on which Limits to Growth was based describing the critical loops involved in global dynamics. (Morrison, 2010)

Subsequently the Meadows and company described and explored, through system dynamics models, policies for sustainability designed to avoid the collapse shown in the 'business as usual' WORLD3 scenarios (Meadows et al, 1974a). Moving along to a full documentation and data for the WORLD3 model used in the *Limits to Growth* describing the structure and assumptions; including all data needed for complete replication of all runs in the popular book. (Meadows et al, 1974b). Finally, the most relevant work from *Limits to Growth* was reviewed in great detail showing that many problems described in 1972 have worsened, as predicted by the model. Ultimately, this study in 1992 argued for a shift in values necessary to create a sustainable and equitable future. (Meadows et al, 1992).

The running of the standard model are shown in Figure 8.2 below as well as the most recent observed trends as compared to that predicted back in 1972.

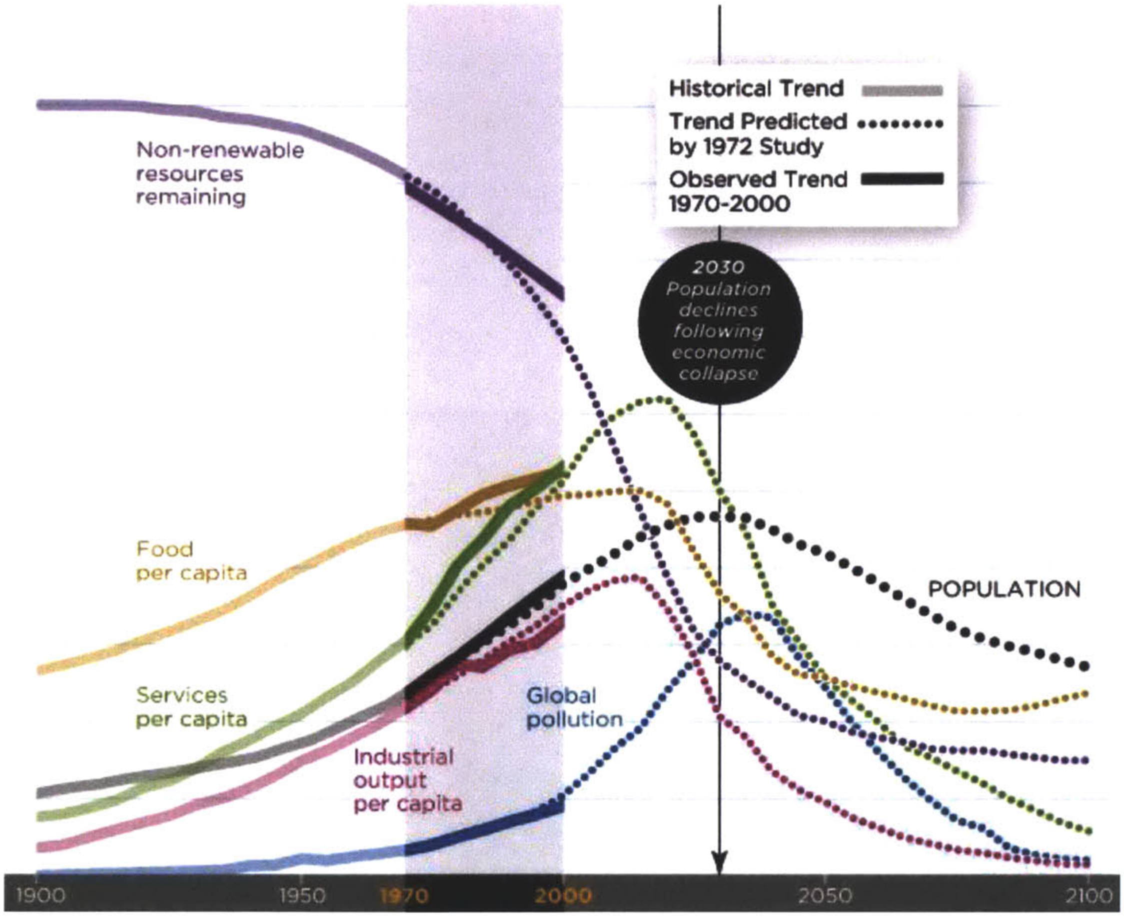


Figure 8.2: Limits to Growth Model and comparison of 1972 predictions and observed trends.

There is reasonable predictive power in the initial model being very predictive of population, industrial output per capita and global pollution, and slightly under or over predicting factors like food per capita, services per capita and non-renewable resources. The most important part to note is that the standard "business as usual" model predicts an economic collapse around 2030 and a radical and harsh decline in human population through mechanisms of resource gaps, pollution and pandemics as primary drivers and other follow on items like war and violence as follow on factors.

In this the dominant loops in the decline from Figure 8.1 becomes the balancing loop of "B2 – Erosion of Carrying Capacity" and the reinforcing loop of "R4 – More is Always Better Loop". The study looked at alternate scenarios to create what is called a soft landing or the stabilized scenario. This alternate scenario is shown in Figure 8.3 in the upper right hand corner as compared with the standard runs showing collapse at the center.

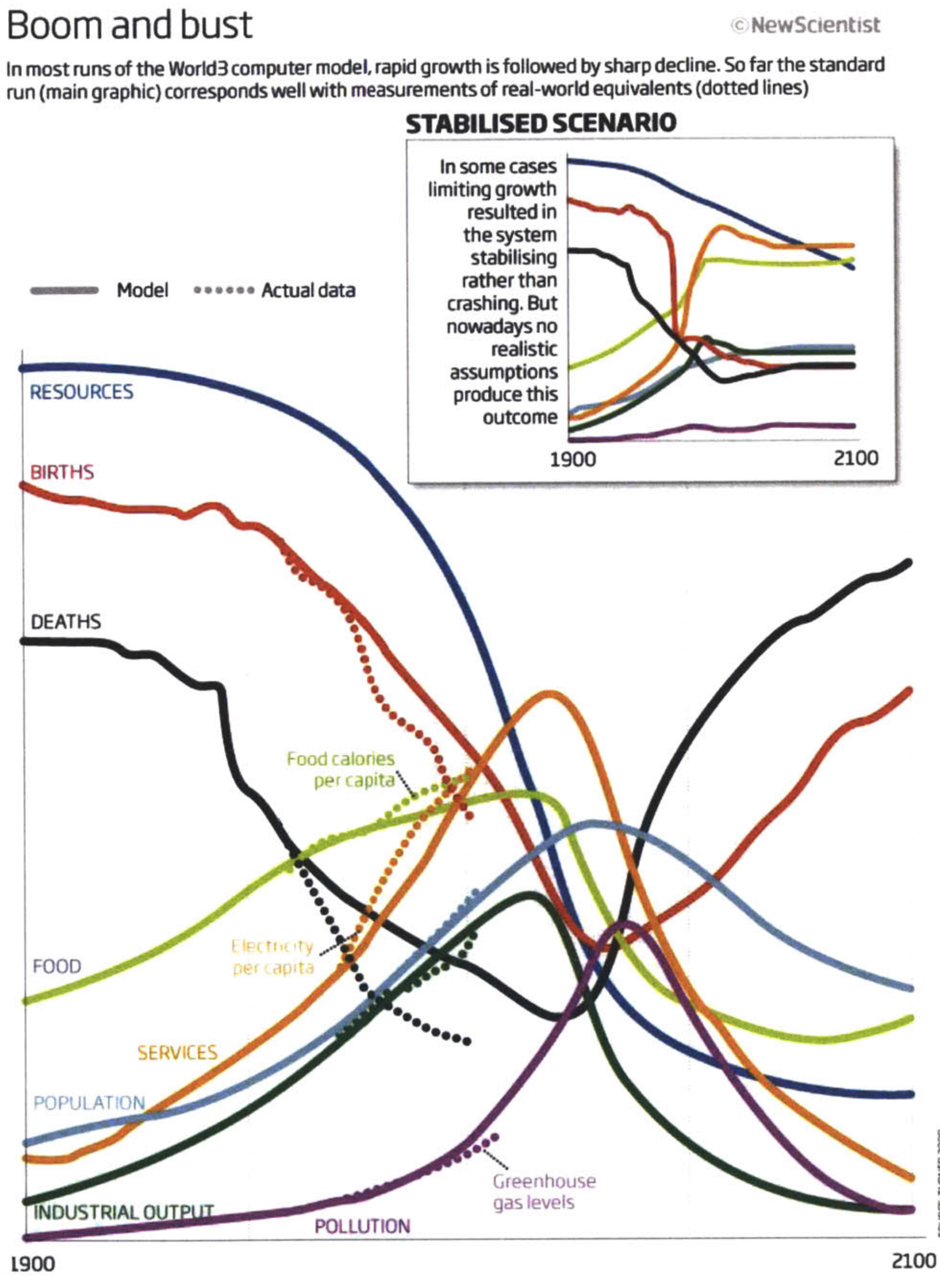


Figure 8.3: The stabilized scenario from Limits to Growth (upper right hand corner) compared to standard runs.

The biggest loops that must compensate for the massive effects of B2 and R4 is actually two loops of "B4 – Demographic Transitions Loop" and "B3 – Technology Fix Loop". These two drivers are discussed as the technology innovations and implementation (in the broadest definition of the term technology – which includes social and physical or combination technologies as described in Section 2 and the fundamental day-to-day change in behaviors, mindset and values needed. For the former, these are essentially the quite of socio-technical innovations of the kind we have been dealing with, some structured around the core of a physical technology while others are structured around a key social technology. For the latter piece, one can imagine that the idea in the so-called developed world around the increasing need to increased accumulation of goods and wealth beyond the prior generation and beyond the individual's own past is a trend that could be curbed in values, perhaps going for more egalitarian options that maintain competition but redefine what "good" or "better" looks like as humanity.

The *Limits to Growth* model and reassessment essentially put the weight on values redefinition as primary and the technology innovation as secondary but both extremely important to the stabilized scenario that we seek and avoiding collapse. This means that the **design and propagation of impactful socio-technical systems** as we have been describing is the critical activity and process that needs to be worked on. This is the critical problem we are trying to solve and so in this section we undertake the task of defining how we are fairing in the current state in bolstering loops B4 and B3 with respect to the 11 conditions, how certain key proposals for improving the current state fair against those conditions and what a new proposal and organizational model may look like that optimizes for the 11 conditions.

In order to understand and describe the current state, we will at first start with the dynamics of global problem solving as described by Sachs (Sachs, 2008). Sachs is the renowned director of the Earth Institute at Columbia University and has presented the most expansive description (built from first hand experience and analysis) of the agents, the groups and the dynamics of how global problems are solved and global goals are achieved (or not achieved). In Sachs model the following actors are important:

Public Sector
Private Sector
Not-for-Profit Sector (including foundations and academia)

Sachs describes the roles that each of these actors have in the global landscape and these are shown in Table 8.1. The mechanics for how these sectors play together is described at a high level for the majority large global problems related to environmental sustainability, disease eradication, population stabilization, poverty reduction etc. in Sachs' work. The perception of the problem usually happens within a small group of experts, generally scientists and this can often be many years before they have am impact on public or private sectors. Examples of this sort of early identification in the Not-for-Profit sector have been the discovery of climate change, population explosions and desertification or even pandemics. Specifically it is usually the research university or academic center that finds out about this several decades before the public at large is cognizant of has formed a set of opinions. As the hypotheses are confirmed with facts, or bolstered by catastrophic events that push or accelerate the information into the public eye, the public becomes more aware. If the problem is large enough, there are usually some collective global agreement that is facilitated by the Public and the Not-for-Profit sector that lay out some initial goals or needs to act but don't produce the action at the scale needed have impact globally. Examples of these are for instance the United Nations Framework Convention on Climate Change which was a global treaty ratified at the Rio Summit in 1992 acknowledging climate change, the scientific discovery of which took place several decades before.

Table 8.1: The roles of various sectors in global problem solving (Sachs, 2008)

SECTOR	ROLES
Public Sector	Funding basic science
	Promoting the development and demonstration of early stage technologies
	Creating a global policy framework for solutions
	Financing the scale-up of successful innovations and technologies
Private Sector	Investing in R&D, often with public funding
	Implementing large-scale technological solutions in partnership with the public sector
	Existence through profit
Not-for-Profit Sector	Public advocacy
	Social entrepreneurship and problem solving
	Seed funding of solutions
	Accountability of government and private sectors
	Scientific research, notably in academic institutions

Solutions begin often in the foundation part and academic parts of the Not-for-Profit sector or the Private sector. There are also groups of experts called epistemic communities or communities of expertise (CoEs) that look at initial solutions. Examples of these include the Merck effort to eradicate river blindness or the Rockefeller Foundation's efforts to champion high yield seed varieties or universities' efforts to grow the ability to replace or control ozone depleting chemicals. Often the Public sector provides seed funding for this sort of work along with the policy shifts needed. We can call this phase of solution development the Proof of Science step, where the hint of global potential is identified. This nomenclature we adopt from the technology roadmapping process we discussed in Section 6 and the depiction laid out in Figure 6.7.

Implementation of early solutions are largely done in the Not-for Profit sector parts. Often starting with NGOs (non-governmental organizations) play a role in getting the initial impetus up to do early pilots at smaller than global scales. The foundation and philanthropic parts have a large part to play in providing resources and funds at this phase and public service organizations like Engineers without Borders do implementation. Let us call this the Proof of Technology/System-level Concept stage. We use the broader definition of "technology" here as described in Section 2 that is the social, physical or combined socio-technical systems.

As these early Proof Technology activities take hold and are effective, the learning continues often accelerated by a global or regional disaster that demonstrates the need for heightened public action (for example the 9/11 attacks in the case of violence or Hurricane Katrina in the case of climate change). It becomes clear that market forces alone cannot solve the problem; they are perhaps to prone to the loop of "R4 – More is Better" where the definition of "better" is not the definition needed to resolve the global problem. At this stage we see the Public, Private and Not-for-Profit sectors combine to create some global agreement or treaty and perhaps a plan of action. These have occurred in the past with items such as ozone depletion, HIV/AIDS control, malaria control and poverty eradication. There might be some associated funding or financial/economic framework might be agreed to or crafted. Some of the pilots at this point from the earlier phase can be tested more rigorously for proof of behavioral, regulatory, ethical, operational and other issues. We can call this the Proof of Robustness stage for these socio-technical systems.

After this phase is the implementation or global scale-up which in these cases can last years to decades. Based on the *Limits to Growth* base model, we may not have that much time to implement these solutions and scale them up. Nonetheless, the dynamic has usually worked in manner where Private sector and Not-for-Profit sectors enable Public sector fueled push to implement. Ideally, the planet itself will pull for these solutions, but likely for the most challenging endeavors, the change task will be hard and solutions may have to be pushed. Some examples of these endeavors are the substitution of ozone depleting chemicals, HIV/AIDS treatments being made accessible to thousands of people in the developing world etc. Even population growth curbing was backed by international funds (Sachs, 2008). If the targets for getting better are set properly, than the effective scale-up is metered appropriately and the change is deployed broadly. We can call this the Scale-Up and Global implementation phase.

If we represent these phases with the gate-type nomenclature introduced in Figure 6.7 and the different actors as stakeholders, we can create a stakeholder map for each phase of this dynamic (Crawley, 2010). This flow is shown in Figure 8.4 in the framework of a stakeholder flow map. The flows here are greatly simplified even with respect to the high level dynamical scheme presented by Sachs above. An observation that can be made even in these simplified flows is as that we approach the later stages of the global solution implementation, the flows between sectors becomes heightened and complicated. As defined, the challenge level at these later stages tends to go up and the full design and adoption attributes of the challenge definition of Section 2 comes into full flourish and effect.

Let us take for granted through inductive reasoning that all of the socio-technical endeavors we are talking about are at a challenge level above 6. We will refer to the dynamic and organizational model from discovery to implementation as described as Fix Model 1.

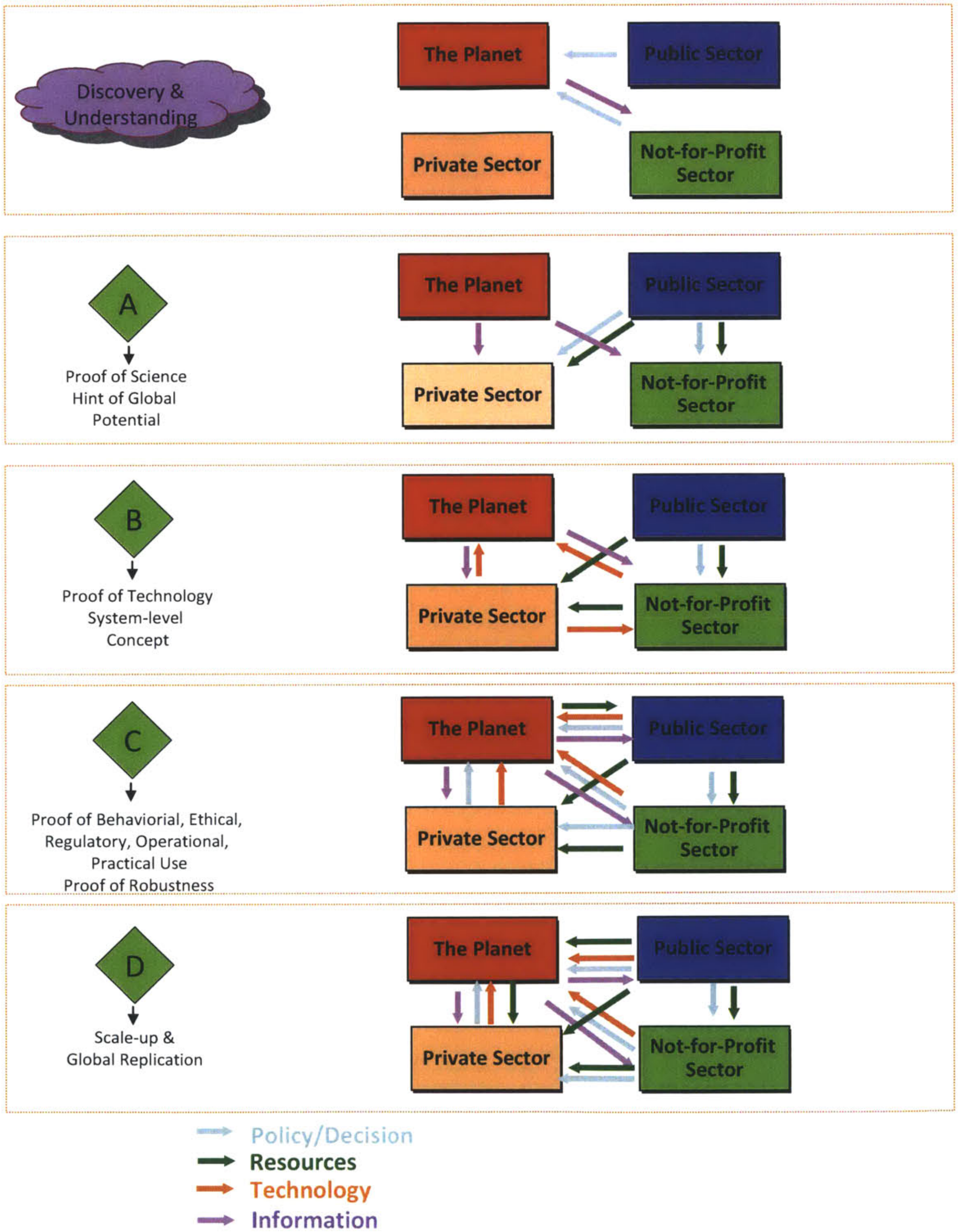


Figure 8.4: Fix Model 1 – the base case scenario as to how socio-technical solutions to global problems.

The Fix Model 1 scheme presents several problems as we progress through the cycle when viewed through the lens of the 11 attributes. If we conduct the assessment against these conditions in the framework of the POS GPA created in Section 6, we find the POS GPA of Fix Model 1 to be 1.18/5.0. This logic is shown in Table 8.2.

Condition Number	Condition Name	Present or Absent	Quality of Condition	Details
1	Burning platform and compelling destination	Present	C	The case for change is often not clear until catastrophe occurs and is left to chance, often very slowly from the Not-for-Profit sector.
2	Single visionary who creates and evangelizes system-level design	Not Present	F	There is no visionary overlooking the system, and very often the visionary for any specific socio-technical solution is not legitimzed from the beginning.
3	Understands and balances technical and moral implications	Present	C	Again left to ad hoc and can often get caught in non-science based political churn.
4	Six to nine key players	Not Present	F	There are a multitude of players in any of these schemes and often the 6-9 critical synthesizers are lost once we traverse the Proof of Technology stage and rarely if ever present for the Scale-Up (which may take more than a lifetime).
5	Relationship with the world is like a campaign or movement	Present	B	Difficult to align the messaging across the sectors unless mandated by policy.
6	Abandon false paths, maintain true north	Not Present	F	Not clear as to whether ineffective solutions are killed fast enough for the good of the larger benefit and target. Information from the planet gets diluted.
7	Intrinsically motivated brilliant or dedicated resources with adequate resource rate	Not Present	F	Not entirely clear if the system is ideally suited to attract and reward the most dedicated people to solve global problems vs. those that can be more lucrative and driven solely by market forces. Funding is often diffuse.
8	Deploying prioritized, globalized resources while aggregating, synthesizing local innovation	Not Present	F	This rarely occurs and even NGOs find it difficult to share innovations.
9	Ideas good or bad get transmitted without variation	Not Present	F	There is very little ability to prevent unwanted mutation of concepts as they propogate across, thus very good semes may get killed due to mutilation of true intent.
10	Visualization of information, interdependencies, status, monitoring	Present	C	This is getting slightly better with the advent of information sharing and communication technologies, however the interdependencies and concerted action (often needing some to pause and others to advance) is missing.
11	Segregation of decisions and actions by time cycles	Not Present	F	This is clearly not present as there is no body that is coordinating the discovery to scale-up and implementation with a strategic view of 50-100 years. Even the United Nations is at best reactionary for the majority of its endeavors.
			1.1818182	

Table 8.2: Assessment of Fix Model 1with a calculated POS GPA.

By our predictive exercises in Section 6 and Appendix B and by inductive reasoning we gather that Fix Model 1, (the status quo) is insufficient. Sachs presents several upgrades to Fix Model 1 with a study of the Global Fund to Fight AIDS, Tuberculosis and Malaria which he purports provided a new global architecture that bolsters global cooperation, and puts additional focus on science, technology and the combined efforts of the Public, Private, and Not-for-Profit sectors. Sachs' identifies 4 key conditions for success in the global problems. They are goals, technology, implementation and finance. He does not define these as well as the 11 conditions that we have defined in this study and is missing several of the important considerations contained within them. Nonetheless, he shows how the Global Fund was able to meet these 4 key conditions. A track record for the global fund can be seen in Figure 8.5.

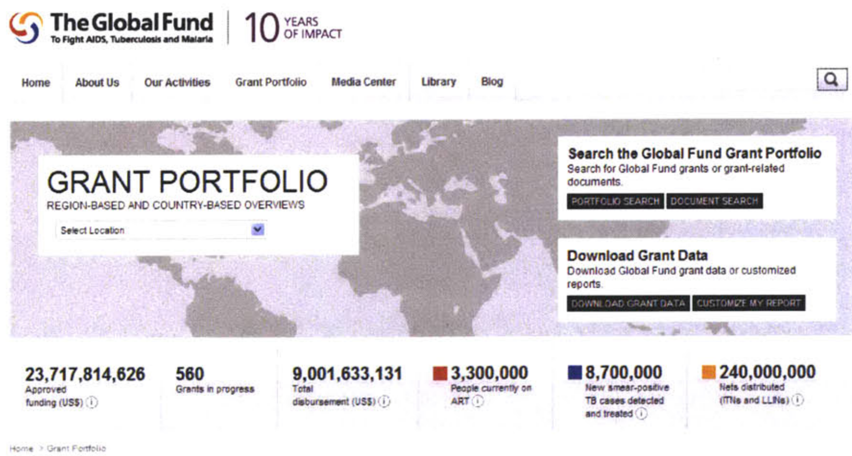


Figure 8.5: The track record for the Global Fund for AIDS, TB and Malaria as of 2012 (from Global Fund website).

The fund works through the collection and disbursement of funds in an efficient manner to local efforts, either for the purchase of medications or equipment and facilities geared towards curbing these diseases that so impact the developing world. From this we can arrive at recommendations for a "Fix Model 2" with the following attributes that Sachs presents:

A new financial architecture of sustainable development: Based on the Global Fund to Fight AIDS, TB and Malaria, there would be other funds established or bolstered to create a very similar pooling and granting system. These would include:

> *Global Fund for an African Green Revolution – focusing on sustainable agriculture, high yield seeds, high efficiency water and land use*
>
> *Global Environment Facility – focusing on sustainable energy, adaptation to climate change, biodiversity and dry lands management and managed by UNDP, UNEP and the World Bank*
>
> *UN Population Fund – focusing on universal access to sexual and reproductive health services to stabilize population to 8 billion by 2050.*
>
> *Global Infrastructure Fund – focusing on pooled funds for poorest nations and infrastructure*
>
> *Global Education Fund – focusing on basic education.*
>
> *Global Community Development Fund – focusing on cross-sector initiatives that are focused on total community transformation*

Social venture capital: The concept of having global funds primarily for proving out initial concepts that would come directly from foundation dollars.

Basic R&D funding mechanism: A means of mobilizing research and development efforts to benefit the world in addition to the national pooled funding model that operates for institutions such as the NIH. This requires additionally the revamping of the role of the research universities to be more global and less focused on national interests.

System for bolstering NGO innovations: A means of taking innovations developed by NGOs (such as microcredit) and scaling them up to global scales. This requires acknowledging and bolstering the unique role of the NGOs in driving change beyond what market forces and governmental actions can account for.

More ubiquitous utilization of networking tools: A means by which the ever expanding capabilities of social tools, the Internet and mobile technologies can be directed towards global development efforts.

Cultural shifts in individuals: Fix Model 2 includes some fundamental recommendations for the each of us as global citizens. This includes being more aware of science and fact, being aware of global affairs and travel (either locally or internationally) to seek to understand perspectives from people from walks of life different than one's own.

UN "delivering as one": As the only true global, intergovernmental organization has a unique role in the world. The three main functions are a means of communication for global governments in a way that levels playing fields as much as possible, a secretariat and administrative body for global treaties and agreements on goals, chronic issues such as development help and mobilization body for acute emergency relief from items like environmental disasters or national governmental collapse during the times of conflict (relief groups or peacekeeping forces as examples). The immensity of the UN has created a level of complexity that often defies the ability to act as one unified organization centered on the accomplishment of global goals. For example, how does UNICEF and UNEP work together within a nation? Often this requires the establishment of special groups that take on special coordination functions for larger goals like the Office of the High Representative for Least Developed Countries, Landlocked Developing Countries and Small Island States a part of whose mandate is ensuring the full mobilization and coordination of all parts of the United Nations system, with a view to facilitating the coordinated implementation of and coherence in the follow-up and monitoring for the Least Developed Countries at the country, regional and global levels. Often coordination activities, like for the implementation of UN Security Council Resolution 1325 calling for equal footing of women in security matters did not have a clear oversight structure in place and has been left to NGO groups to oversee the various UN bodies in its implementation (see Appendix A). Sachs proposal is to fix this UN alignment and action problem on a broader scale.

This system above (Fix Model 2) in aggregate is estimated to cost about 2-3 percent of global income (Sachs, 2008). When we analyze Fix Model 2 in light of the 11 attributes we find the following POS GPA to be 2.91 out of a possible 5.0. The calculations for this are shown in Table 8.3. While a marked improvement from the status quo, our predictive model would indicate that even these enhancements are not enough to increase POS GPA to a level that would bolster our confidence that we have an effective system for solving the largest contemporary challenges.

Condition Number	Condition Name	Present or Absent	Quality of Condition
1	Burning platform and compelling destination	Present	C
2	Single visionary who creates and evangelizes system-level design	Not Present	F
3	Understands and balances technical and moral implications	Present	C
4	Six to nine key players	Not Present	F
5	Relationship with the world is like a campaign or movement	Present	B
6	Abandon false paths, maintain true north	Not Present	C
7	Intrinsically motivated brilliant or dedicated resources with adequate resource rate	Not Present	B
8	Deploying prioritized, globalized resources while aggregating, synthesizing local innovation	Not Present	B
9	Ideas good or bad get transmitted without variation	Not Present	B
10	Visualization of information, interdependencies, status, monitoring	Present	C
11	Segregation of decisions and actions by time cycles	Not Present	B
			2.9090909

Table 8.3: The POS GPA for Fix Model 2 with Sachs enhancements

The difficulty of using the case of the Global Fund as an example is, while it has been of tremendous global benefit, it fails to account and aggregate other important initiatives conducted by other groups that have been initiated through cross-sector alliances. Prominently missing in its complete impact to the global fight against AIDS, TB and malaria is some of the contributions of pharmaceutical companies like Merck/MSD, Pfizer, Bristol-Myers Squibb and Lilly and others. If aggregated, these activities contribute to often **53 times** as much as those funds disseminated by the Global Fund. For instance in a study done by the Center for Science in Public Policy (Hudson Institute, 2004) it showed that the total disbursement from the Global Fund was $150 million, whereas the total from all international organizations was $5.89 billion (including WHO, Unicef and the World Bank). Pharmaceutical companies disbursed and additional $2.1 billion in the form of medications and aid. As wonderful as the structure and concept of the Global Fund is, it fails to aggregate and visualize the total impact and the total efforts towards the fight against these deadly diseases. Thus, aside from the inherent deficiencies that Fix Model 2 has with respect to the 11 necessary conditions, there is a major facet that is missed. This is the axiom stated below:

> *The conception and implementation of an ideal global system for solving the greatest contemporary challenges is in itself a challenging human endeavor. Thus the system itself must have purposeful and directed work to design and propagate. The system for tackling the most challenging human endeavors must be on the list of the most challenging human endeavor to be tackled.*

In order to have a successful global system to change the current trajectory shown in *Limits to Growth* in the time allotted, we must make concerted efforts to design the global system itself and treat that system as large human endeavor itself. In this Fix Model 2 falls short, even though it has some of the vital components structurally defined. The creation of a master global system in essence becomes a new contemporary Manhattan Project that as built and piloted and scaled up manages, prioritizes and links other contemporary Manhattan Projects. In the implementation of this new global system, we would attempt to alleviate the deficiencies seen in Fix Model 2. This premise forms the crux of Fix Model 3, which has the steps and estimated timing shown in Figure 8.6.

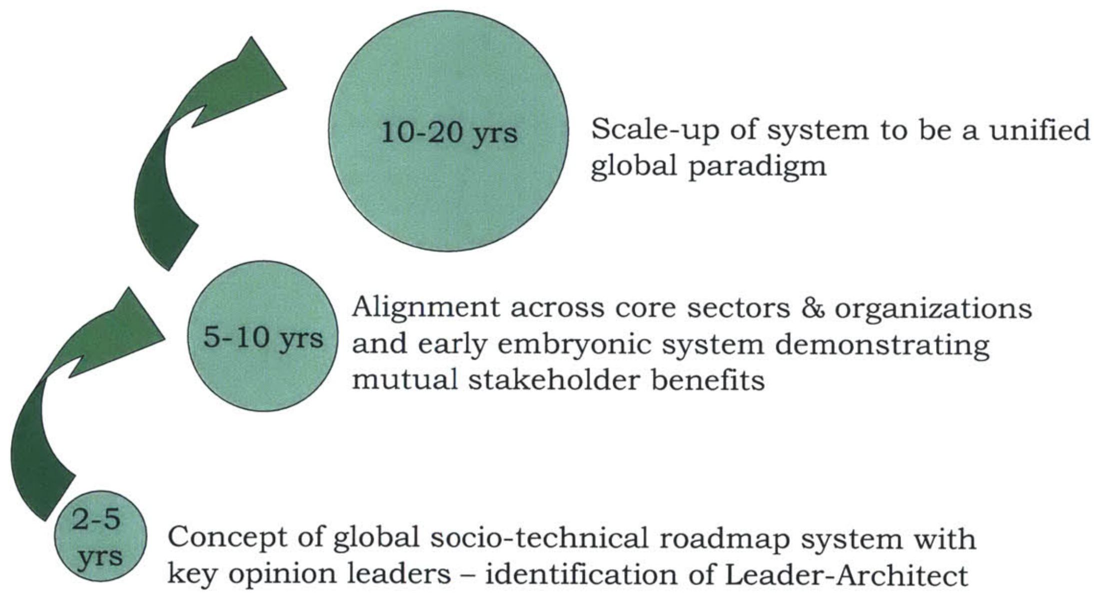


Figure 8.6: A plan for creation and implementation of a global system to manage large scale human endeavors.

In the figure, it can be seen that the central artifact in this proposal is the concept of creating global socio-technical roadmaps. As was seen in a more localized study in Section 6 within a large global organization, the implementation of a system to manage technology maturity and implementation can be highly effective in achieving large scale transformations and creation of stakeholder value in short periods of time. It adds the benefit of coordinating work, prioritizing initiatives and linking them to avoid duplication and create synergy and aligned action around a common set of goals, which in the case of our study in Section 6 was the positive, step change impact to human health. But it was also seen that the implementation of such a system requires a Leader-Architect to take hold and craft the vision and group of subject matter experts and thought leaders to implement and pilot. The larger vision must be maintained through the early initial steps and the whole endeavor must be managed in a series of iterations between design and implementation while giving key attention to stakeholder and change management. The proposal for our new global system is indeed the crafting of a global system for managing, prioritizing and linking large human endeavors in the form of what we will call socio-technical roadmaps. By modifying Figure 6.7, this conceptual system can be visualized. This is shown in Figure 8.7.

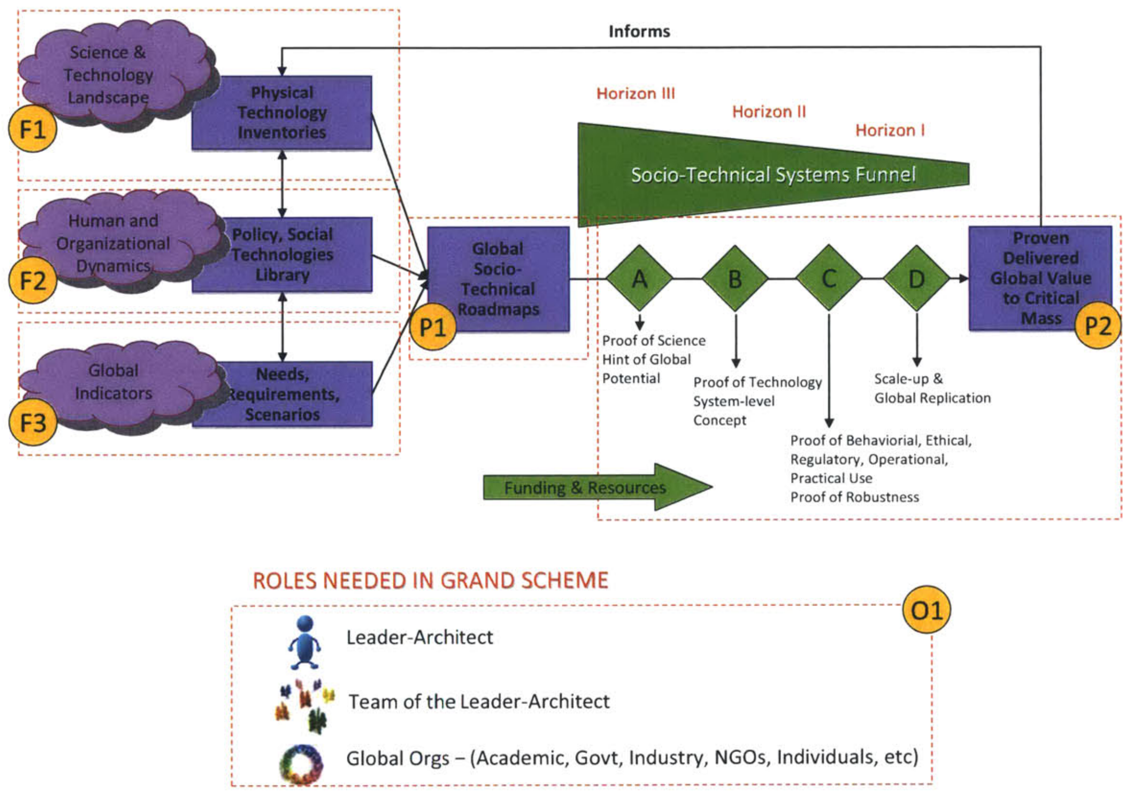


Figure 8.7: A new global paradigm for managing, prioritizing and linking large human endeavors.

The gates of technology maturity identified by Fix Model 1 are shown, while the discovery phase has been broken down into the subsystems F1, F2, F3 indicating the various sources from which they come. At the center is the currently non-existing set of global socio-technical roadmaps. What is most important about the sub-system P1 is not the mere fact of its existence, but the alignment from the organizational entities shown in sub-system O1. Without this global alignment, the roadmaps themselves would be meaningless and concerted action and management could not be achieved in the timeframe we have.

The informatics needed to manage such a system are immense. The relationships between all the various components of the system above can be demonstrated using a well-known enterprise systems management tool known as the X-matrix (Nightingale, 2010). Mario Montoya has demonstrated the ability to morph X-matrices in creative ways to achieve the maximum benefit from this form of MDM (Montoya, 2010). We propose an X-matrix to enable the visualization of the elements in the process above and we will term it the "TeX-matrix" in reference to the socio-technical systems it looks to manage and link. The TeX-matrix construct is shown in Figure 8.8 below.

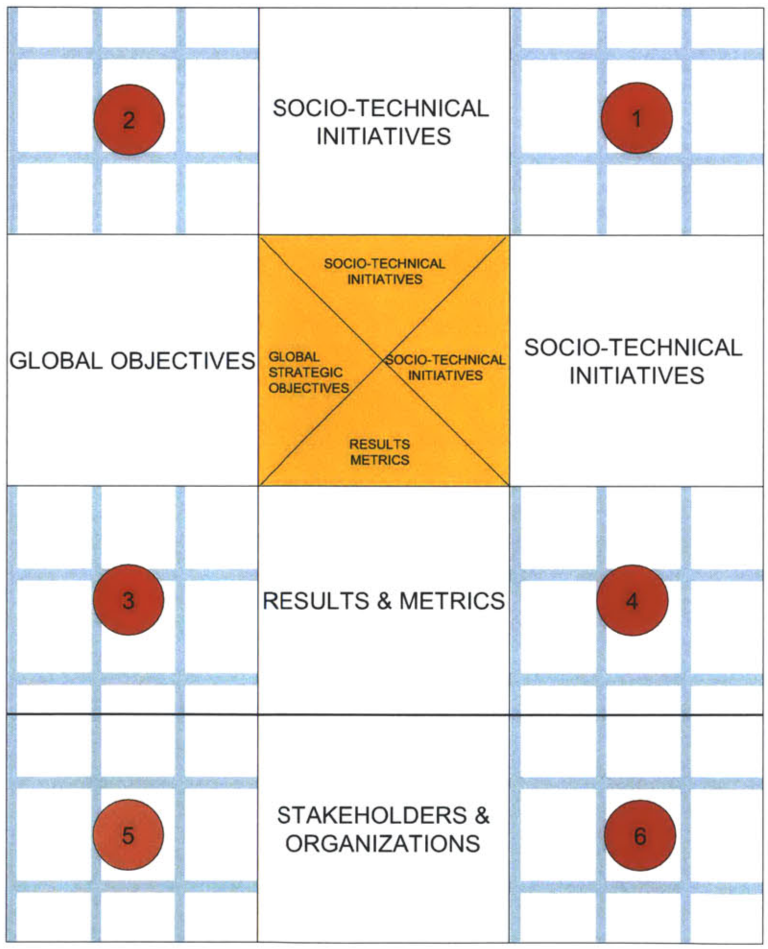


Figure 8.8: Depiction of a TeX-matrix, a modified version of the X-matrix frequently used in enterprise systems design and management.

Each one of the gridded areas represents some sort of a correlation matrix between the two adjacent data fields. The TeX-matrix is of course at the heart of it an MDM but conceived in a topology that puts the most important relationships next to one another and serves to answers important questions of the larger system. In describing this, we start with the correlation matrix in quadrant 3. This is the linkage of global goals (through global agreements and such) to measures that indicate progress or embody targets. Examples of global objectives are establishment of the elements of a culture of peace (see Appendix A) or the eradication of certain diseases etc. The metrics are measurable targets, for example those embodied in some of the SOFI goals, shown in Figure 1.1. These results and metrics can be driven or achieved by certain socio-technical initiatives and this correlation is held in quadrant 4. Conventions can be developed to show the complexity or typology of these dependencies, for example whether an initiative is directly contributing to a measure or enabling a measure to be impacted, or whether it is in the near term or the long term. Initiatives would need to be tagged based on what stage of maturity they were in as indicated by Figure 8.7. To demonstrate some of the technologies that could have major impacts (be they physical or social) we share some examples of promise in the mindmap of Figure 8.9 (Ferris, 2011).

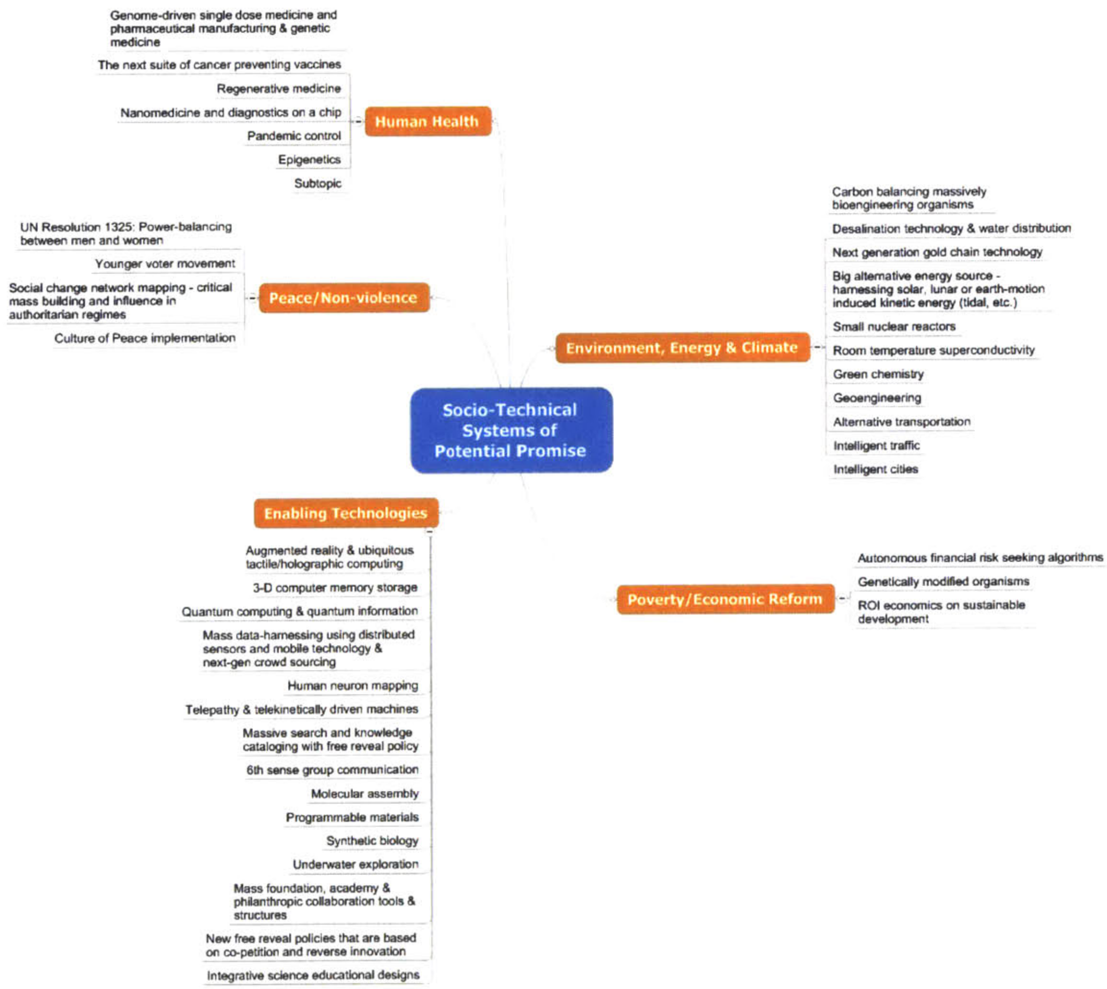


Figure 8.9: Certain technologies of promise that need to be harmonized and aligned towards achieving global goals.

The examples shown are a mix of fundamental technologies very much at the Proof of Science phase, such as the mapping of neurons, others have passed the Proof of Value phase and need to be scaled up globally such as green chemistry. The farther one gets from the academic and research setting, the harder it is to shuttle learning from one area to another. The academic setting allows for a well understood citation system, but the real world of messy implementation and scale-up will require a new paradigm of global knowledge management. Thus some of the enabling technologies listed deal with massive data sets and how to visualize, search and organize this complexity. It should be noted that such problems have been solved in the past, for example Boeing in the creation of an aircraft manages at times the interconnections of over 500,000 components (Rhodes, 2009). The challenge of today is how to manage this in a decentralized manner. IBM and Google are companies that are working on these challenges today (examples such as the global word citations project and Watson) so such technologies are not out of the realm of possibility in the near future (Mollick, 2009).

The quadrant 1 of the TeX-matrix is where a small innovation is introduced to the standard X-matrix tool. Here instead of new adjacent data fields, we introduce the concept of having a DSM (dependency structure matrix) between the initiatives. This type of interrelationship is vital and within the correlation grid we can introduce some fundamental ways in which initiatives need to be linked. A code can be developed to relate the various initiatives to one another either for sharing information, people, funds, or even for the purposes of sequencing work so that one bolus of work can be utilized by another initiative. This sort of alignment and visibility is now completely lacking in our planet but this global system can enable such a democratized tool utilizing technology that we have existing today. The endeavors that require much greater oversight and global governance can then be teased out of this analysis and made visible to the millions of stakeholders involved. A simple representation of factors that could lead us to this global governance is shown in Figure 8.10.

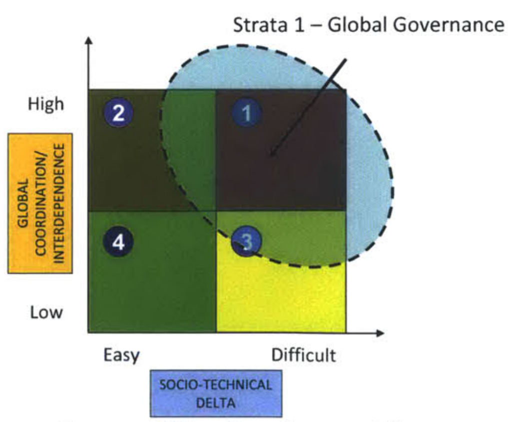


Figure 8.10: Some factors that could lead to the need for aggregation of some initiatives under global governance

For communication and public campaign purposes, the quadrant 2 provides adequate connections from the large global objectives to the initiatives in the global database.

Some dashboard can be developed for global visualization of this in the same manner as sites such as Charity Navigator (http://charitynavigator.org/) and GiveWell (http://givewell.org/) do for NGOs and charitable organizations. Data visualization projects like this are happening today allowing for representation of tremendous relation complexity in easy ways (Chapman, 2011). Figure 8.11 shows two examples of visualizations, one a categorization of the strength of nations in 23 areas of science and the next is and example of the number of citations made across scientific journals. This type of power can be used to represent these quadrants of the TeX-matrix.

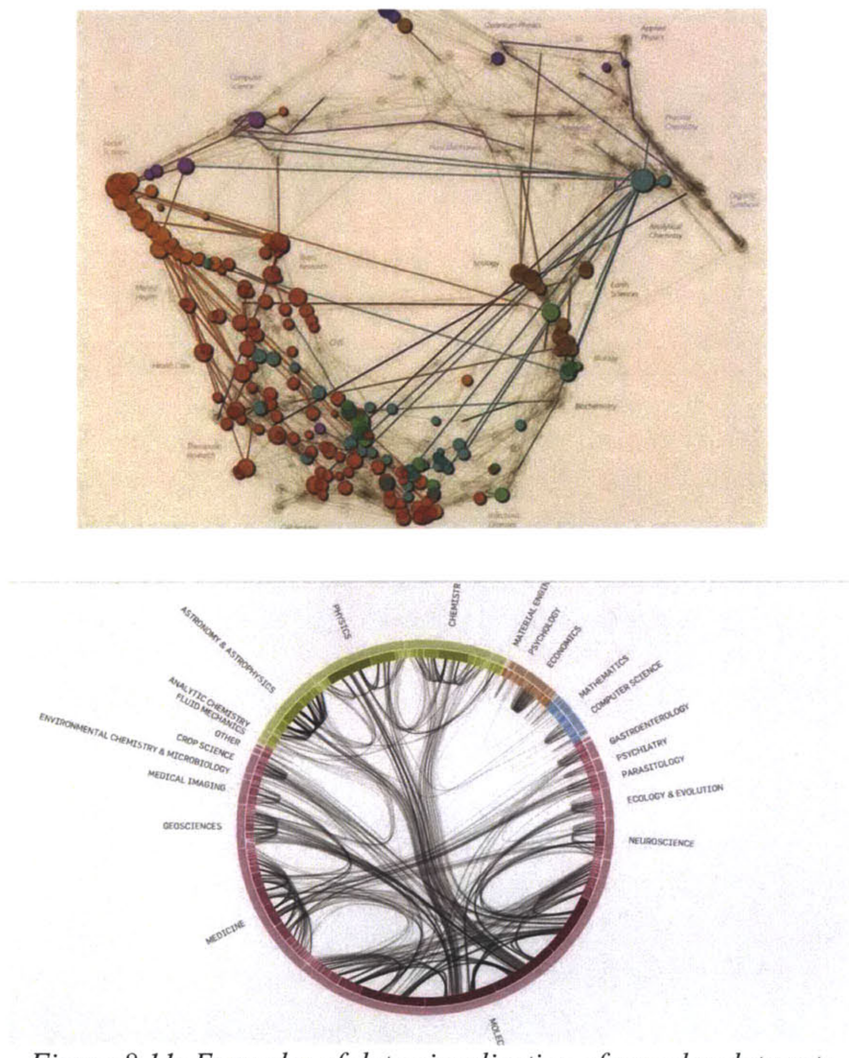


Figure 8.11: Examples of data visualization of complex data sets

The final 2 areas of the TeX-matrix show the organizations and resources that must be linked either to the objectives or to the initiatives. This is the area where the greatest coordination must be built into the system. For example, from the research point of view, there are several bleeding edge research centers in just the United States that need to aligned on their activities that can contribute to the SOFI improvements. Schrage of MIT's Media Labs published a list of "red-hot centers of American genius" (Schrage, 1999). This list is shown in Appendix C but include Not-for-Profit sector entities like the Santa Fe Institute, Private sector entities such as Pixar and Public sector entities like the Immigration and Naturalization Services. If the innovations and learning from these institutions are to turn into real change fast enough, the coordination of these groups must be amplified and put into constructive harmony and resonance. The list in Appendix C is merely meant to be examples of institutions that need to better collaborate. Of course aggregation bodies are coming into existence, like the InterAcademy Council (IAC) which is a forum of 94 national academics of science that present excellent global assessments to advise decision makers providing a viable means of achieving some of the front end systems F1,F2, F3 of the Figure 8.7. The IAC has already published reports on climate change and the role of women in the world of science, but as mentioned before is the connections through an end-to-end system of implementation and scale-up of technologies.

Lastly, the TeX-matrix and the global paradigm must be managed as mentioned before utilizing segregation in time of decisions. Using the Time Shell Model presented in Section 4 we can envisage the organizational sub-system O1 to be segregated into four shells.

> *Shell 4: Global loop consisting of representatives from the all sectors and a Leader-Architect, deciding on goals with legitimacy from all constituencies. Responsible for managing the socio-technical roadmaps.*
>
> *Shell 3: An analytical loop that connects and coordinates the actions of all the bodies with in the global system in the context of the socio-technical roadmaps.*
>
> *Shell 2: All of the execution arms that carry forward work and activities regardless of where in the continuum they are with a level of inter-body connectivity on annual cycles.*
>
> *Shell 1: The true value chain, the part closest to planet and the people where the design, installation and realization of socio-technical systems happen.*

The building of the a new global paradigm for managing, prioritizing and linking large human endeavors entailed in Fix Model 3 will require a tremendous amount of work and coordination, but the seeds of a high level plan is laid out in Figure 8.6.

In the end we are left with one over-arching problem. Who will do this? How will Fix Model 3 come together and gel and who will initiate the spark that aligns the various pieces we already have on the planet towards an integrated global view? Who will take the first step? Of course, our premise is that in the beginning there must be a Leader-Architect, who enjoys legitimacy and has great vision to make the case for change and take the first careful steps in building the system. But can this work? It is the final conclusion of this paper that it can indeed work. The establishment of a global organization has indeed happened several times in the history of humanity. The latest is of course the United Nations. The UN was borne out of the scourge of World War II, providing a burning platform and a compelling destination and amongst its crowning achievements is the Declaration of Human Rights. But for this new global paradigm as envisaged in Fix Model 3 to succeed we need the conception of a brand new type of global organization. One that combines all sectors of the world, Private, Public and Not-for-Profit under new rules and global goals. Perhaps the UN can become this new organization or perhaps it needs to seed the inception of something larger of which it is a part, working hand in hand with the Private sector more closely. The key to this new global organization will be the proof and belief that partaking in the larger system will be of mutual benefit for all stakeholders, both in the immediate term and in the long term. It must start with a commitment by the players involved to commit to a common artifact of the socio-technical roadmaps and the various interconnections that need to be mapped and made real. Fix Model 3 is possible, but the most variable element is the existence and action of the Leader-Architect who can give it birth and make it grow.

SECTION 9: CONCLUSION

In this study, we have been successful in developing a set of necessary conditions for success in the most challenging human endeavors. We defined our concept of "challenge" and developed a semi-quantitative approach to defining challenge level by looking at the dimensions of the difficulty of design of the solution and the difficulty of the propagation of that solution across the populations that it needs to influence to make a positive impact. The conditions themselves were defined through an exhaustive meta-study of the most relevant literature on the topic utilizing a taxonomical scheme that allowed for grouping of multiple ideas underneath common ideas. This process yielded 11 primary conditions that appear and are validated across a diverse and expansive set of recorded and cited management theories. We tested the premise that all these conditions are necessary on the most challenging endeavors by testing their absence or presence in some of the most crucial events in the stories of the 20 greatest engineering achievements of the 20th century. We also tested them in a rougher sense against many of the mega-projects carried out in the past 100+ years or are being carried by humanity today. This provided confidence in the concept of necessity.

We tested the optimality question of each of these conditions by inventing a simple scale for mapping the level of each condition (beyond just mere presence or absence) and the level of results or outcomes achieved by endeavors within a specific multinational company with global reach and particular mission related to global human health. This helped us realize that the degree to which each condition is achieved becomes important the more challenging the initiative becomes. We also took time to delve into great detail on a specific, multifaceted endeavor carried out at this company in which the 11 conditions were purposefully coded and tested for the results and level of success. By studying in great detail a specific live case (conducted over the last 3 years); we were able to show the specific choices that can be made with knowledge of the 11 conditions to increase the probability of success of a highly complex human endeavor, albeit contained within the bounds of a large company.

With these detailed empirical and case analyses in hand, we covered a theoretical construction from the first principles of evolutionary biology, cognitive science, neuroscience, psychology, and various other natural and social sciences to present the causal reasons why these 11 conditions should matter, and demonstrated that the fundamental science bolsters the premise of the existence of these conditions as the most important, proved their necessity and also reasoned why there are optimal points for their application and existence within an endeavor.

With this framework and evidence in hand, we assessed current and semi-enhanced approaches to solving the current big four issues of health, poverty, environment and peace and demonstrated their inadequacy utilizing the 11 conditions analysis. We laid out the axiom that the creation of a new global system is needed to manage large human endeavors and that creation itself would be a challenging human endeavor. With this principle in hand, we laid out a blueprint for a new global paradigm for managing, prioritizing and linking large human endeavors around socio-technical roadmaps called

Fix Model 3. We ended with a simple conclusion, that Fix Model 3 had all of the relevant components in existence on the planet today. The most variable element is the existence and action of the Leader-Architect who can give it birth and make it grow.

At the very end, it comes down to a question of vision and leadership. But rather than wait for a Leader-Architect to be born, it is incumbent on each of us to assume that we are it. Only with a million failed attempts to create this new global paradigm will one eventually succeed in finding the magic blueprint that will indeed save humanity. It is with each inspired failure will the die be cast for the right system.

So in conclusion, this study serves to be a call to action to all who engage in its ideas – may you try your hand at taking on this challenge and driving this change. May you wield your talents towards the creation of this new global paradigm. May you find strength in the knowledge that you tried for all of us, and just through the act of trying you have been a part of paving humanity's path to stability, survival and success.

SECTION 10: FUTURE WORK

The breadth of this study did not lend itself to delving into great depth into many topics, if given the gift of time, we would have chose to research in greater detail. It is with that notion that we present this section that lists a series of potential areas of additional study and research.

Section 2:

1. A more quantitative way of assessing challenge level that goes beyond the semi-quantitative scale developed.

Section 3:

1. A further development of a classification scheme for all management theory allowing for the connections of various ideas and potentially connecting them to more basic human thoughts and cognitive processes.

Section 4:

1. A fully fleshed out model of the Leader-Architect and an examination of Leader-Architects from the past. One potential theory is that every Leader-Architect goes through an inflection point (or several) through out their lives, whereby the depth of their expertise meets up with a challenge and ideal circumstances to propel them to a new level of achievement.
2. Understand the role of communication and communication style in various Leader-Architects especially in instances where language itself is not enough (reference Diderot, Bacon, Nietzsche).
3. Are practices like learning, sleep, daily routine important to Leader-Architects or are significant variation expected.
4. A deeper understanding of the role of the influential people surrounding a Leader-Architect.
5. Further development of the concept of the "seme". Develop a theory as to how semes may describe some fundamental dynamics of technology, such as the existence of dominant designs or the movement of technologies in the Kano model. Understand how the role of human architecture (both cognitive and physical) contributes to the selection, combination and propagation of semes.
6. Catalog the most effective ways of relational visualization and develop new concepts of visual comparative evaluation tools for large data sets as like the SAPARP.
7. Truly flesh out and model (under various organizational situations) the concept of time-based segregation of observations, decisions and actions. Can this model be used to explain the effectiveness of Lean Enterprise processes like Hoshin Kanri? Examine ways that fluff:stuff ratio can be used to maximize value-added time

between shells (Schrader-Cournoyer). The premise is that the ratio of cross-talk that is "fluff" related and that which is "stuff" related between shells can be made the most efficient if the fluff related matters are reduced.

8. Develop a new project management paradigm (that is less reliant on deterministic movement) that allows for the insertion of social technologies or tactics such as "brainstorm and iterate" or "role play solutions" or "do-learn-plan" into its architecture for development of large complex projects that require much iteration.
9. Correlate network structures (that consist of people and consist of technologies) and properties with ideal ways and tactics for designing a campaign or movement or propagate memes and semes. The concept here is that people network structures are important for memetic propagation, but technology and people networks and interfaces are important for understanding semetic propagation.
10. The utilization of approximate knowledge by Leader-Architects to progress large systems forward. There is a notion that approximations are an important part of large systems decision making. These have often been called back-of the-envelope or Fermi problems (as Enrico Fermi had a propensity for doing such). Approximate knowledge can be loosely defined as when the counter statement is highly unlikely and yet the actual statement is fairly insightful - and has at least two sources of independent corroborating information from the Leader-Architect's experience. Can approximate knowledge be used for large scale systems problem solving that takes cross-discipline SMEs and gives them a challenge and a finite period of time (say 3 hours) and this is done in parallel between groups, then the resultant outcomes are presented creating a wider design space.

Section 5:

1. A deeper study of the National Academy of Engineering list with attention towards the 11 conditions.
2. Understand whether value creation is achieved through taking systems from a dynamic state to a stable state (temporal change rate reduction) and from a complex state to a simple state (perceived complexity reduction).
3. Understand the impacts on civilizations and technological progress historically of having an identified enemy vs. having a more amorphous and ill-defined set of problems.
4. Create a model for how the various sub-components of an organizational model interact (process, people, structure, knowledge, assets and culture).
5. Detailed meta-study of mega-projects worldwide and assessment of necessity, optimality and results (including aerospace, airport build or expansion, building, canal, dam and hydroelectric, military, stadium and sports venues and international sports infrastructure, information technology, oil and gas, port, rail and rapid transit, bridge and highway, science, planned city and urban renewal, spaceflight, water infrastructure, environmentally related mega-projects).

Section 6:

1. Creation of a more detailed guide book for creation of technology roadmaps that account for social technologies as well.
2. Understand the different ways technologies flow from unarticulated need and un-provenness to articulated need and maturity. Often the traversing happens through aggregation of various sub-technologies in new and novel ways (semetic combinations) or they happen through true invention (birth of a brand new seme).
3. Fully flesh out the concept of STRAP (shuttle to the right accountability promptly) as a useful tool in an organization that is highly complex where decision rights and roles are unclear.
4. Create a more quantitative means of assessing the extent of use of the 11 conditions.
5. An observation within the company is that there are tons of great ideas and best practices that are generated by the creative minds within the organization. The problem is, too many companies are resorting to going outside for getting help, even for the most simple of things from consultants, rather than looking at themselves for ideas and sharing. One reason this problem exists is the lack of efficiency in being aware of the stuff, being able to sort through it to see what is useful and then applying it in iterations. Aware - Sort - Modify - Apply. This is problem can be solved by creating a role within the corporation called the Innovation Sharing Office. A nimble (almost journalistic) approach for being in the know, having enough depth to understand needs and then ideate and cross-fertilize. To create a center of excellence for being a network node for information and sharing between different areas within a large corporation. The role becomes: Observe - Identify Needs and Gaps - Connect - Ideate on Modifications - Share Potential. What the office should absolutely not do is the diminish creativity by creating "in-breeding" through too much internal cross-fertilization. This office can be combined with the benchmarking office and scouts for linking to external sources of ideas.
6. Understand the hurdles as technologies make their way through the various gates of maturity from analytical challenge to inventive challenge to innovative challenge to persuasive challenge.
7. Consider a new model for the technical leader of the future:
    a. Ability to manage by influence as much as by direct authority/direct line supervision, across divisions, areas, geographies etc.
    b. Ability to drive active participation a shared objectives/shared metrics environment
    c. Be able to achieve a balance between maintaining role clarity, role discipline and scope of groups while being able to adapt roles and scope as business needs dictate
    d. Ability to build a vision, mission and a group identity where one does not exist
    e. Valuing coaching, mentoring, and learning at the same level as directing, coordinating and prioritizing work – particularly personnel from groups OUTSIDE their own

f. Providing the incentives for employees to assist with OTHER people's objectives as a large part of their own objectives
g. Ability to manage non-traditional career paths and succession planning for organization
h. Ability to drive integrated science-business solutions
i. Embodying the inclusion behaviors

Section 7:

1. A deeper understanding of the loss-uncertainty equation as a practical way of mapping individual barriers to change.
2. Study whether or not there are universal models or symbolic equations for universal mechanisms. The evolutionary algorithm is an example of such a universal model, with the same agents and agent relationships and dynamics regardless of which context it is placed into (from biology to business). Others like the propagation of something through a substrate (as embodied in the Darcy equation) can represent another example of a universal mechanism often found in nature. This could be a semantic way of representing semes as well.
3. A deeper understanding of the cognitive processes that lead to innovation or new ideas. One observation is that serendipity often happens when one is not directly thinking of the problem and understand why that should be so.
4. Study the impact of leaders (or Leader-Architects) on mirror neuron activity through FMRI (functional magnetic resonance imaging).
5. A theory that describes the Kahneman thresholds for in the context of segmenting changes in to traversable thresholds. Understand or explain how this happens in the minds of individuals with different visualization capabilities (from early adopters and innovators to laggards) both in the active sense of when individuals themselves are the initiators of the transition to a new state or a passive sense when individuals need to react to a change imposed on them. The active sense maybe described by the utilization of the theory of anchor points in negotiation theory that set the norm about which negotiations occur. It should be explored whether traversing through changes can be conceived of as a series of establishing anchor points, completing the personal negotiation and then setting a new norm. Additionally understand the link between consequences and Rule 1: Choices have consequences. Rule 2: Risk is the amount of negative consequence of a choice multiplied by probability of that consequence occurring. Rule 3: A rational being aligns choice with risk tolerance.
6. Understand how mental models mechanistically are created and then present limitations to future understanding of new causal relationships. The ideas could be that the limitations of understanding. The same framework and sets of logical rules that allows an observer within a system to define the limits of his/her understanding or capabilities within that system is the root cause of the limitations themselves. This premise maybe generalized to explain the limitations of broader human understanding.

Section 8:

1. The concept of fall of civilizations and how that is tied to knowledge and capability of that civilization. That is, when a civilization has acquired enough capability to impact its own existence, it has simultaneously developed the knowledge to understand that impact and thus there exists a small window of survivability where that knowledge can be used to curb demise.
2. Explore more deeply the attributes of the new global organization within in which the UN, NGOs, academies of science, foundations, academic centers and industry resides that joins all sectors of the planet towards achieving common goals. Create the framework of incentives that would allow the new global paradigm to work. This presents a way to craft future worlds in an experimental but highly rigorous artificial environment. Do platforms like Second Life allow for a testing of global models?
3. Embed the concept of being able to test global organizational models through combinations of simulations, role playing and computer models.
4. Explore the role that individual volunteerism can play in enabling mass human change.
5. Understand the chasm dynamics that may be at play when an idea needs to move from the Proof of Science past the Proof of Technology phase. For example, there is a true implementation dilemma for the most leading and bleeding edge natural and social science and a potential growing rift between academic and the application level in the real world. The theory is that there is an abundance of solutions available from academics that can solve local problems, but administrators (in both the developed and developing world) do not embrace solutions due to a lack of familiarity with the systems and constructs (journals, symposiums etc.) in which these solutions are discussed. The solution is potentially a growing class of informational translation people who take complex ideas and studies and translate them and simplify them into broadly implementable plans. This would be a new budding profession of the Idea Engineers.
6. Understand more fully the dynamics of disruption and if they are important in the creation of a new global organization that can disrupt the incumbent global structures. Understand whether or not NGOs for instance can one day disrupt the UN.
7. Define the components of the new value system that counteracts "More is Better" loop that would represent the next stage in human values evolution. For instance, does power truly have to come from the ability to do harm to other individuals or can this be redefined, in other words what is the variable sensitivity of humans to burning platforms vs. compelling destinations?
8. The concept of private sector knowledge drain (e.g. Eastman Kodak and the amount of chemical and imaging knowledge that is lost to humanity) and how knowledge management around socio-technical roadmaps can preserve this for future generations.
9. Further develop the tool of the TeX-matrix.

10. Crowd-source the creation of the first version of socio-technical roadmaps, or utilize the Delphi method to create them.
11. Examine situations where cross-sector sharing of principles are helpful, for instance the measurement of value from private to NGO (e.g. charity evaluation tools using investment ideas) and the idea of sustainability in investment considerations from NGO to private (e.g. the importance of taking the long view in corporate decisions). For instance the need to begin to apply product development concepts to world improvement. For example, say an NGO that is looking for donations started from the point of defining themselves as offering a product, like a service, a popular commodity or an image. Then the improvement body would go about looking at doing "Voice of the Donor" and well as the "Voice of the Receiver" and try to really analyze their vectors of differentiation and how best to make their product unique and valuable.

KEYWORDS:
Choice, Action, Benefit, Cost, Risk, Unknown, Liability, Consequence, Tolerance, Knowledge, Ability, Opportunity, Challenge, Purpose, Talent, Skill, Desire, Probability, Event, Vision, Happiness, Strategy, Causality, Judgment, Influence, Diversity, Reward, Connectivity, Exposure, Environment, Impact, Result, Drive, Motivation, Luck, Lineage, Learning, Encouragement, Enablement, Data, Attachment, Philosophy, Decision, Option, Uncertainty, Scenario, Planning, Complexity, Chaos, Flexibility, Control, Analysis, Threat, Optimization, Problem, Goal, Scope, Solution, Freedom, Value, Disruption, Creativity, Innovation, Idea, Independence, Execution, Focus, Adaptability, Leadership, Adaptability, Opinion, Error, Pedigree, Prioritization, Rules, Failure, Law, Competition, Demand, Supply, Balance, Equilibrium, Compromise, Evolution, Governance, Completion, Commencement, Operation, Enforcement, Empowerment, Mutation, Meaning, Communication, Information, Instruction, Stimulus, Response, Feeling, Organization, Performance, Transformation, Technology, Implementation, Realization, Portfolio, Program, Project, Passion, Network

APPENDIX A: PERSPECTIVES FROM A LEADER-ARCHITECT ON BALANCING TECHNICAL & MORAL IMPLICATIONS

One of the 11 conditions that are most difficult to explain is the concept of a Leader-Architect balancing technical and moral implications. In Section 4 we examined the fact that a Leader-Architect has honed his/her skills to an expert level in their craft to the point where they can make pragmatic choices and tactical decisions that preserve the greater good and intent of the movement that he or she is driving. In order to examine more closely this concept we look at two examples of world-changing social technologies born within the United Nations. The social technologies in question are the Culture of Peace Declaration and Program of Action and UN Security Council Resolution 1325. In these two instances we will explore the role of Ambassador Anwarul Karim Chowdhury, a Leader-Architect who played pivotal roles in crucial instances in the birth of these two important social technologies. Through information gathered through interviews directly with Ambassador Chowdhury we were able to learn some of the decision making nuances and choices that faced him. We will see that Chowdhury had to exercise careful judgment and diplomacy, balance firmness and flexibility and employ principled pragmatics in the preserving the larger good and intent of these two movements. Chowdhury is a global leader and diplomat most noted for his work on development in the poorest nations, global peace and championing the rights of women and children. By the time he took on the challenges of the Culture of Peace and UN Resolution 1325, Chowdhury had well developed a level of technical expertise that made him a master of global negotiations. Aligned with the archetype of the Leader-Architect we have described in Section 4, he had indeed put in well above his 10,000 hours of active practice in his craft.

Before launching into the accounts of these social technologies, it is important to understand the structure of the United Nations. The United Nations is comprised of several main bodies. The General Assembly is the main deliberative body comprised of all member states. It creates mandates that drive the work of the rest of the United Nations. The Security Council has primary responsibility for the maintenance of international peace and security and is comprised of 5 permanent member states and 10 non-permanent member countries holding 2 year terms. The Economic and Social Council coordinates the economic, social and related work of the UN. The International Court of Justice is the principal judicial organ of the United Nations. It settles legal disputes between states and gives advisory opinions to the UN and its specialized agencies. The Secretariat carries out the day-to-day work of the UN and does the work of administering peacekeeping operations, surveying economic and social trends, preparing studies on human rights. As mentioned in Section 8, it is the Secretariat that would be able to create change and coordinated action of the UN in delivering global goals.

<u>Culture of Peace</u>

The story of the Culture of Peace is one of the General Assembly. As defined by the United Nations, the Culture of Peace is a set of values, attitudes, modes of behavior and ways of life that reject violence and prevent conflicts by tackling their root causes to solve problems through dialogue and negotiation among individuals, groups and nations. Through the UN Resolutions A/RES/52/13: Culture of Peace and A/RES/53/243: Declaration and Program of Action on a Culture of Peace, eight essential areas of global action are introduced. They declare that in order for peace and non-violence to prevail we need to foster a culture of peace through education, promote sustainable economic and social development, promote respect for all human rights, ensure equality between women and men, foster democratic participation, advance understanding, tolerance and solidarity, support participatory communication and the free flow of information and knowledge, and promote international peace and security. Much like our 11 conditions, all eight conditions stated here must be met in order for a culture of peace to take hold.

The UN Declaration and Program of Action that embodies these eight conditions was adopted by the UN General Assembly in September 13, 1999 and has been termed by many as one of the greatest documents produced by the United Nations, equal in its importance to the Universal Declaration of Human Rights. It codifies a means by which the UN can achieve its initial purpose which is the elimination of conflict in the world and the proactive establishment of peace for future generations. It serves to operationalize very specifically how to transition from violence to peace.

The ratification of this document was to not be an easy undertaking. Many countries of the developed world, particularly the EU, felt that the mere statement of the need for moving from a "culture of war" to a "culture of peace" (which was embodied in the culture of peace draft proposals) acknowledged the fact that there was indeed a culture of war existing on the planet. It is easy to see why there might be some sensitivity here. Much of the world's plight was based in large part to the influence of the developed countries of the North and to acknowledge the need for a culture of peace would be to acknowledge the fact that power and influence may have been obtained through violent means with controlling peaceful ends. The acceptance of a transition from a culture of war to a culture of peace was thus completely unpalatable to the many countries of the North based primarily on historical concerns. The second chief concern from the North was the idea that a culture of peace would prevent the ability to mobilize when human rights were being violated through military action.

For almost a year prior to its adoption, the Culture of Peace Program of Action had not even been considered in the General Assembly, largely blocked by technical maneuvers executed by countries opposed to its wording and the core of its ideas. One dignitary of these opposing nations requested that the precise wording "culture or war" be taken out as such a culture did not exist in the world. The US opposed the elevation of the right to peace as a fundamental human right citing the difficulties that may produce in the ability to start a war of necessity, particularly where other human rights were being violated. On the other side, the farmers and nations that supported the resolution did so in a principled manner and were eager to preserve the essence of the document without modification and with utmost purity.

Despite all of these blockages the resolution was finally considered in the General Assembly primarily due to the efforts of Chowdhury to champion the cause. He orchestrated tactically over 75 different diplomatic discussions took place over nine months of informal negotiations, likely more than any other time in UN history over a resolution. Each discussion built on each other, providing learning and nuanced considerations for each subsequent conversation. The technical details of these discussions were complex and required a seasoned hand: the unique considerations that must be made by a Leader-Architect and his six to nine core individuals. By this time, Chowdhury had already been in the diplomatic service for over 30 years, having served in a variety of important and influential roles in the UN, so the worked and what did not work was clear in terms of a mental model. But each negotiation required Chowdhury to abandon false paths along the way allowing to keep inching towards the ultimate goal of consideration of the resolution at the General Assembly and eventual global adoption.

Figure A.1: The UN General Assembly

Each dialogue required intimate knowledge of the positions of the nation being spoken, its consequence history and even the style and approach of its representing diplomat and negotiator. However, with each step, he and his team had to keep in mind that the actual acceptance of this monumental resolution was the greater good and that is truly what was at stake. Each discussion informed the grander plan with detailed understanding and visualization of which areas were non-negotiable and which areas provided some wiggle room for Chowdhury to make progress on alignment. It was because of this diligent and untiring effort, the resolution was finally considered in the 53rd session of the General Assembly in 1999, a year after it was first crafted. Some concessions had to be made to get the resolution considered including the removal of the idea of a "culture of war", the reordering of the eight actions to have education be the leading item (where the North wanted human rights and the South wanted economic and social development to be in the lead) and the removal of a pooled funding scheme by which the Secretariat could execute actions on behalf of a culture or peace.

But on the last day of the 53^{rd} session, the resolution was still not adopted as the final bit of negotiations had to be conducted with great tact and skill by Chowdhury and his facilitating colleagues for many hours. Appearing non-partisan and maintaining his credibility as a liaison between parties was incredibly important according to Chowdhury. He obviously had a strong interest in the well being of the least developed countries but favoritisms from him in the role of a mediator would have signaled the death knell for the initiative. He thus had to make clear attempts at seeing the issue from both ends and be willing to make some hardening compromises as long as the main language and ideas of the culture of peace were not diluted. The pressures mounted, as had the resolution not been approved that day, it likely would have taken permanently off the agenda from that point on or would have faced even greater hurdles to get back on. Here are the two choices that Chowdhury faced in the delicate balance of technical and moral implications.

> *Choice 1: Keep stronger language in the resolution (such as the culture of war) and make very few concessions, but risk not having the resolution considered at all or if considered then only pass by a roll-call vote where there would be a deep divide between the South and the North. The South would vote "yes" and the North would vote "no", essentially leading to divisions in implementation and action. A technical victory but a loss of symbolic global solidarity would be the outcome.*

> *Choice 2: Creatively craft language representative of provisions that allow for the unanimous adoption, acceptance and consensus by ALL member states of the General Assembly. Utilize the technical strength of carefully selected language and key concessions that would ultimate be less divisive but allow for the primary and most impactful principles of the Culture of Peace resolution to be maintained.*

Chowdhury felt that a resolution passed through roll-call would be much less than ideal and set these epics change for humanity off on the wrong foot. It is his technical skills in driving negotiations that even allowed him to have this option open to him and in the end, he decided on Choice 2, preserving the greater good over a technical victory.

The main ideas and wording of the culture of peace were retained in the final document and creates one of the grandest plans for peace in the history of the UN which continues to gain in importance and gravity as the years progress.

> *"I believe that this document is unique in more than one way. It is a universal document in the real sense, transcending boundaries, cultures, societies and nations. Unlike many other General Assembly documents, this document is action-oriented and encourages actions at all levels, be they at the level of the individual, the community, the nation or the region, or at the global and intellectual levels ... This document really goes ahead in terms of bringing in various subjects that the Assembly has rarely touched in its 50 years of existence." – AK Chowdhury, on last day of 53^{rd} meeting of the General Assembly during which the Culture of Peace Program of Action was accepted by consensus of all members of the General Assembly.*

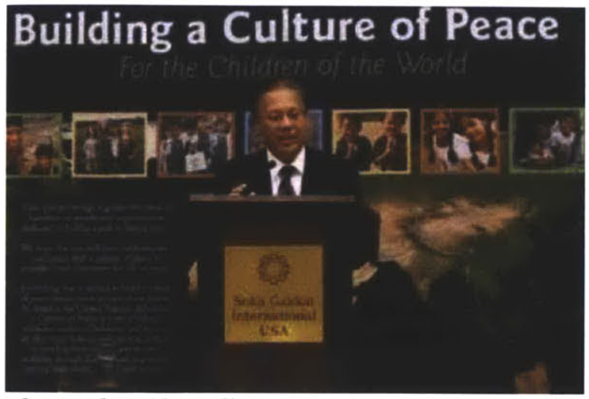


Figure A.2: Ambassador Chowdhury speaking on a Culture of Peace

Resolution 1325

In October 2000, the UN Security Council adopted Resolution 1325. Until this point, violence against women during conflict and war was not an international concern. Through adoption of this resolution, the Security Council essentially declares this to be a matter of global security. Ultimately it calls for the need for women to be active participants on an equal footing with men in peace processes and in peace work.

Most recently, the Nobel Peace Prize was awarded to Ellen Johnson Sirleaf, Leymah Gbowee and Tawakkul Karman for their work in assuring the safety of women through non-violent means and for trying to achieve women's rights to fully participate in peace-building work. We will see how UN Resolution 1325 codifies much of the concepts for which these women were awarded the prize. It lays forth unequivocally that democracy and sustained peace cannot take place unless women obtain the same opportunities as men to influence developments at all levels of society at all times (and most critically at times of conflict). It is a political framework that makes women and a gender perspective relevant to all aspects of peace processes- from peace agreements through peace support operations and planning for refugee and other war affected to post-conflict reconstruction processes and the restoration of the social fabric of a broken society and the pursuit of gender equality relevant to every single action of the UN Security Council. It can be forever used as a tool for advocacy and lobbying, negotiation, leverage, inclusion in peace processes, and protecting rights and demanding political accountability. It also makes the following key commitments:

- *Inclusion of a Gender Perspective at All Levels of Decision-Making*
- *Gender Perspective in Secretariat Reports and in Security Council Missions*
- *Protection of and Respect for Human Rights of Women and Girls*
- *Gender Perspective in Post-Conflict Processes*
- *Gender Perspective in Peacekeeping*

Having assured the adoption of the Culture of Peace Resolution a year prior, Chowdhury was again at the center of being the Leader-Architect for getting this ground-breaking resolution passed. This time it was in his role as the President of the Security Council of the United Nations. On the day of the celebration of the International Women's Day on 8th March 2000, he introduced to the connection of women and peace into the agenda of Security Council. This ultimately led to the path to the adoption of Resolution 1325 in October of that year. Yet again, there was a critical divide in the acceptance of this resolution and Chowdhury was able to utilize what is now a deeply studied technical tactic in the UN Security Council for moving this forward. In what can only be described as diplomatic chess at the grandmaster level, Chowdhury was able to utilize tools and implements available to him in creative ways to ensure that this landmark declaration would be initiated. Before we can understand the master strokes taken, it is important to understand the tools the UN Security Council has to influence the world once decisions are made.

The Security Council has itself three principal channels to communicate outcomes. They are the "resolution", "presidential statements" and the "press statement". The only mode of communication of Council decisions or views that is recognized in the Council's Provisional Rules of Procedure is a resolution. While the term "resolution" is not found in the UN charter with reference to the Security Council, it contains numerous formulations, such as "decision" or "recommendation", which imply the adoption of resolutions utilizing some method of achieving agreement not specified. Resolutions by the Security Council are legally binding if made in response to peace threats, security breaches of acts of aggression. They require consensus and a passing vote (that is no veto from a permanent member).

Figure A.3: Ambassador Chowdhury as the President of the Security Council (pictured left is Secretary-General Kofi Annan), 2000

If these are not achievable, the next means through is the use of a non-binding "presidential statement". These are adopted by consensus and can amount to providing political pressure or clearly signal that the Council has taken note of some security related activity and further action may follow. An important thing to recognize is that presidential statement is in meant to be a statement of the Security Council and not just of its President. When making a statement on behalf of the Security Council the President, under the authority of the Council, represents it in its capacity as an organ of the United Nations. Presidential statements are nowadays as a rule are read out by the President on behalf of the Council in a formal meeting of the Council after the text of the statement has been agreed by all the members of the Council in informal consultations of the whole (Talmon, 2003).

Lastly, press statements typically accompany both resolutions and presidential statements, with some explanatory phrasing of the key points of some Council matter. They may also be released independently, after a significant meeting of the Council itself.

In examining these three instruments, we find that the resolution is the only channel that has implied legitimacy in the UN Charter. While presidential and press statements have been around since the inception of the UN, they have not been in marked use since the early 1990s. A tracking convention for the presidential statements for instance did not exist prior to 1994 when the Council began to utilize the prefix S/PRST/ with a number. Since this time, an average of 45 presidential statements per year were being issued by the Council with then a sharp reduction in the early 2000s to about only and average of 21 in the last decade up to 2011. (UN Security Council Report, 2012). One reason for this dynamic is the skillful technical use by Chowdhury of the "press statement" in driving forward a path to adoption of a major resolution as Resolution 1325.

We see as in the case of the Culture of Peace Declaration and Program of Action, Chowdhury faced strong opposition from many Council members against hc ideas behind 1325. Particularly some of the permanent members (US, UK, France, Russia and China) were not completely aligned on the concept of linking so definitively the role of women in peace and security and the statement that there is an inextricable linkage of peace with gender equality. The strength of the idea is that equality, development and peace bust replace the historical inequality between men and women that has spawned a culture of war and violence. In this instance, Chowdhury strongly believed in the greater good, the core of the ideas having been developed as early back as 1979 during the Convention of the Elimination of all Forms of discrimination Against Women (CEDAW). He also had his impending Security Council presidency during International Women's Day, a rare opportunity to take advantage of and make a significant move to drive these ideas forward to a Security Council resolution. He was faced with two choices as we saw in the previous case:

> *Choice 1: Use his time as a member of the Security Council (and President) to drive consensus amongst the members (particularly the P5 members) around these ideas, diffusing dissenting opinion a priori but risking the potential of total inaction.*
>
> *Choice 2: Use his opportunity as a member of the Security Council (and President) to make some bold movement, within the technical bounds of legitimacy that would bring the issue to a head, and force much more rapid consensus.*

The initial plan, according to Chowdhury, had been to adopt a presidential statement, which would have essentially been Choice 1. Interestingly that would have taken a lot of the a priori consensus building dialogue that Chowdhury used ahead of the General Assembly consideration of the Culture of Peace Declaration and Program of Action. But in this case, he sensed that the opposition from key Council members for such watershed ideas was too great to use such a tactic and be effective. He would have to follow a different scheme. After deliberations with his team he was left with some how actualizing Choice 2 as the only viable path forward to preserve the greater good and achieve. The execution of Choice 2 would require a detailed technical understanding of the working and channels available to him in the Security Council. Press statements afforded him this opportunity. Press statements had been used either as factual statements, statements involving sanction related matters, statements to highlight a specific event, such as a terrorist attack, and the last category is the one that Chowdhury would come to legitimize, is where the press statement represents symbolically the same as a presidential statement but differs only in the mode of delivery.

Chowdhury opted for a clear press statement rather than a more formal format when there is an inability and time to reach agreement among Council members to adopt a formal pronouncement (while both presidential statements and press statements are consensus documents and are not voted on, presidential statements required much more procedural formality and buy-in prior to issuance). On several occasions, the trade-off appears to have been between content and format. Chowdhury would start with a more formal format as a matter of tactics and ultimately agree to a press statement in an effort to preserve the substance.

Press statements were initially rare in Council practice in the 1990s, but on 8 March 2000 (International Women's Day), the Council with the Chowdhury as its President issued what may be one of its most seminal press statements to date—the first-ever Council pronouncement on women and peace and security. Chowdhury read a statement during the noon UN media briefing. We see that the execution of Choice 2 would require not only a detailed technical understanding of the working channels available to him in the Security Council, but also the art form of negotiation in actually carrying it through, including even the precision in timing of the actual execution of the act. In the final minutes before Chowdhury was to momentarily halt Council proceedings to make his statement, a key opposing permanent member recommended that the current arch of their discussion on some other procedural issue was too important to delay and that they should proceed through the press briefing period, effectively deferring the momentary pause. Chowdhury, understanding that the moment was at hand and knowing that he had a crucial window to catch the media during the media briefing period, aggressively and deftly (and one could say with unprecedented lack of deference to a permanent member) halted the Council proceedings mid-stream of Council deliberations and took action at precisely the noon hour to make his statement. His choice to go with this tool of the press statement forever changed the emphasis and potential of this tool to drive change and action. Later that year, the Council adopted resolution 1325, referencing the press statement and reiterating one of its recommendations regarding the need for specialized training on the protection, special needs and human rights of women and children in conflict situations.

His own personal account of that day and issued on the 10^{th} anniversary of the adoption of the UN Resolution 1325 underscores the deep importance of this social technology in the plight of the world. (Chowdhury, 2010)

> *"Tracking back from my own vantage point on 1325, International Women's Day in 2000 was an extraordinary day for me and will remain so for the rest of my life. That day, I had the honor, on behalf of the United Nations Security Council as its President, of issuing a statement that formally brought to global attention the unrecognized, underutilized and under-valued contribution women have been making to preventing war, to building peace and to engaging individuals and societies to live in harmony. The members of the Security Council recognized that peace is inextricably linked with equality between women and men and affirmed the equal access and full participation of women in power structures and their full involvement in all efforts for peace and security.*
>
> *The conventional impression of women as helpless victims of wars and conflicts was overtaken, at least in principle, by the assertion of the role of women in fostering peace in their communities and beyond. Thereby, the seed for Security Council Resolution 1325 was sown.*
>
> *The core focus of this action is women's participation at all levels of decision-making and thereby structuring the peace in a way that there is no recurrence of war and conflict. That is why women need to be at the peace tables, women need to be involved in the decision-making and in the peacekeeping teams, particularly as civilians to make a real difference in transitioning from the cult of war to the culture of peace.*
>
> *1325 marked the first time that increasing participation of women was recognized as an objective of the Security Council for ensuring peace and security. 1325 is an impressive step forward for the women's equality agenda in the context of contemporary security politics. As such, its meaningful implementation places a unique and all-embracing responsibility on the international community, particularly the United Nations." - AK Chowdhury, Speech at Women and War Conference, 2010.*

Conclusion

In this appendix, we have examined in some further detail a specific instance of a Leader-Architect and the role he played in the birth of two world changing social technologies. Both the culture of peace and the resolution 1325 are between "Proof of Technology" and "Scale-up" phase as defined in Section 8. Admittedly, global conflict itself allows for the value of 1325 in more representative ways. The Culture of Peace social technology requires more forethought and even more attention to the global movement, proving out pilots and scaling up. Chowdhury's on-going involvement in both these social technologies and in integrating them into the larger socio-technical system highlights the importance of the role of the Leader-Architect. It also highlights the time scale of these global movements. It required 30 years of situational maturity to even have the technology itself be born, and since its inception, it is requiring decades to scale-up and make global impact. It needs the end-to-end involvement of a Leader-Architect to push this along and catalyze the movement and growth of that technology through major inflection points.

What is apparent from both of the cases is the importance of the UN in providing a forum and platfrom where the incumbent power base of the world and the dominant mental models can indeed be challenged. It is one of the view places on the planet where poor nations can wield authority, enjoy legitimacy and drive change. This presents an important perspective that we will term the Chowdhury Doctrine:

> *The UN provides a one-of-a-kind global forum for giving voice to the concerns of developing nations and a unique arena for leverage and meaingful impact. Thus, developing nations must take on a heightened (perhaps disproportinate) interest and role in the maintenance, improvement and innovation behind the UN structure, processes, procedures and organization itself.*

It is this linkage of organizational design and innovation in concert with using the existing systems in new and creative ways that is the crux of the general recommendation of Section 8. The new global paradigm must be fashioned as it is used in a complex iterative dance of do, learning, planning and designing.

Finally the account above is meant to highlight two things. The first is the the immensity and difficulty of the task at hand both in scale and time for world-changing social technologies, and the improbablity of all the factors that need to come together to make true change happen. But more importantly, the accounts are meant to show that real progress can indeed happen when people with purpose and vision act in skillful and informed ways at precise moments that avail themselves. They can change the arch of humanity for the better.

APPENDIX B: A RIGOR LEVEL 1 EMPIRICAL STUDY OF MEGA-PROJECTS

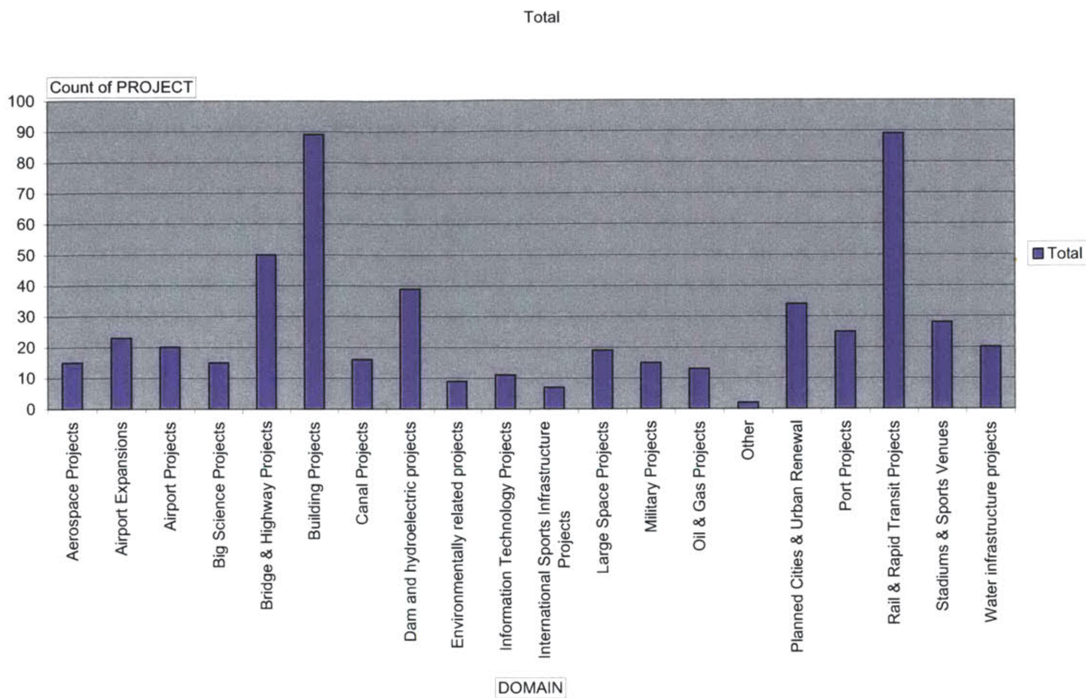
The direct case studies within the Company presented in Section 6 allowed for the combination of three important semi-quantitative analytical tools in our study of challenging human endeavors. Figure 6.17 shows that the correlation between a value called the Probability of Success GPA and the Results GPA increases as the challenge level increases. Put simply, the optimality of each condition becomes more and more important in achieving results the more challenging an endeavor becomes. While this is a fairly straightforward and intuitive outcome, the value comes in the ability in the future to analyze a priori the probability of success of large endeavors on this simple analytical construct and to also a priori engineer success into large human endeavors through success analysis of the POS GPA. To test the validity of this beyond the close-range study done in this section, we apply this concept to a much larger global database of what are known as mega-projects (Flyvbjerg et al, 2003). Flyvbjerg et al presented a concept called the mega-project and this is defined as the following:

> *A mega-project is defined as that which has a lot of public attention and impacts communities, resources, environment and budget. They likely cost on the order of $1B or more to complete and achieve realization by the inflation adjusted valuation of the day.*

This list of mega-projects is fairly large and was initiated by Flyvbjerg in the attempts to study problems such as "optimism bias" and "risk or strategic representation" during the initiation and execution of such projects. Our necessary and optimal conditions construct captures much of this thought process through principles of abandoning false paths and the like. This initial list of mega-projects have been expanded upon in recent years through Wikipedia-enabled crowd-sourcing. The current list catalogues over 500 mega-projects from the days of antiquity such as the Great Wall of China to future intentions such as the Compact Linear Collider (Wikipedia contributors, 2012). The categories covered in the mega-projects list are shown in Figure B.1. A lot of the projects covered are in the area of civil and large public systems projects like Building Projects, Rail & Fast Transit, Bridges & Tunnels and the like. Also on the list are Big Science and Large Space initiatives as well. Interestingly some of the larger event based projects are also shown, such as the Olympics and World Cup events which for a brief period of time require massive attention and by definition present a large challenge level. The complete list of 539 mega-projects considered are shown at the end of this Appendix in Table B.2.

We are able to apply the Results and POS GPA analysis on these mega-projects at a low rigor level and parse them out in the zones defined in Section 2 where challenge values above 5 and 6 are viewed as extremely challenging and the challenge level drops off as we approach bands from 4 and below.

If we parse these mega-projects we find that immediately for the sake of the analysis we are down to 491 projects as they have actually been completed or were stopped due to some failure. The rest are prospective projects or a large bolus of the effort is yet to be done.



Aerospace Projects	15
Airport Expansions	23
Airport Projects	20
Big Science Projects	15
Bridge & Highway Projects	50
Building Projects	89
Canal Projects	16
Dam and hydroelectric projects	39
Environmentally related projects	9
Information Technology Projects	11
International Sports Infrastructure Projects	7
Large Space Projects	19
Military Projects	15
Oil & Gas Projects	13
Other	2
Planned Cities & Urban Renewal	34
Port Projects	25
Rail & Rapid Transit Projects	89
Stadiums & Sports Venues	28
Water infrastructure projects	20
Grand Total	539

Figure B.1: List of 539 mega-projects as an expansion of the Fryvbjerg study

The 491 projects the breakdown in the following challenge level bands using our definitions as shown in Table B.1.

CHALLENGE BANDS	NUMBER OF MEGA-PROJECTS
>6	151
5-6	182
4-5	60
3-4	58
2-3	38
1-2	2
<1	0

Table B.1: The breakdown by challenge level for the mega-projects using a rigor level 1 assessment and our semi-quantitative analysis of Section 2.

This parsing allows us to plot the Results GPA against the POS GPA at each band level. This plot for mega-projects at a challenge level above 6 is shown in Figure B.2.

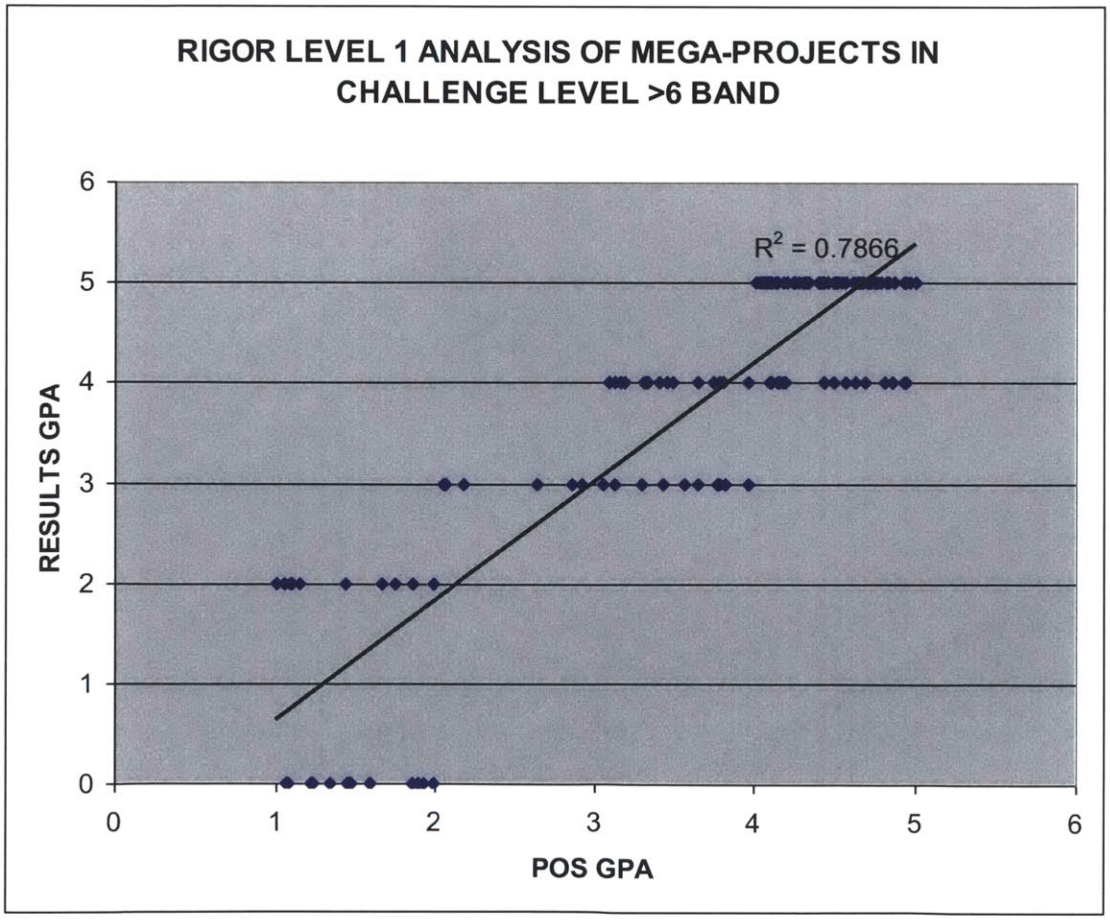


Figure B.2: A linear regression analysis between Results GPA and POS GPA on 151 mega-projects that are at a challenge level greater than 6.

The R^2 value doing a linear regression is 0.7866. This is not the best correlation possible however for an empirical and variable dataset such as this, the point being made is a slightly different that the value of the regression with the band level. Rather, as we demonstrated in the analysis of necessity in Section 5, it is the decrease in this correlation as we decrease the challenge level. As we have demonstrated in this thesis, the importance of the presence or optimality of each of the conditions to the success of the endeavors diminishes as the challenge level decreases. Thus we would expect, as we saw in Section 5, that the regression value would decrease as we repeated this analysis for each lower challenge band level. This meta-study was completed for the 491 mega-projects and the plot of the linear regression coefficient or R-squared value is shown in Figure B.3.

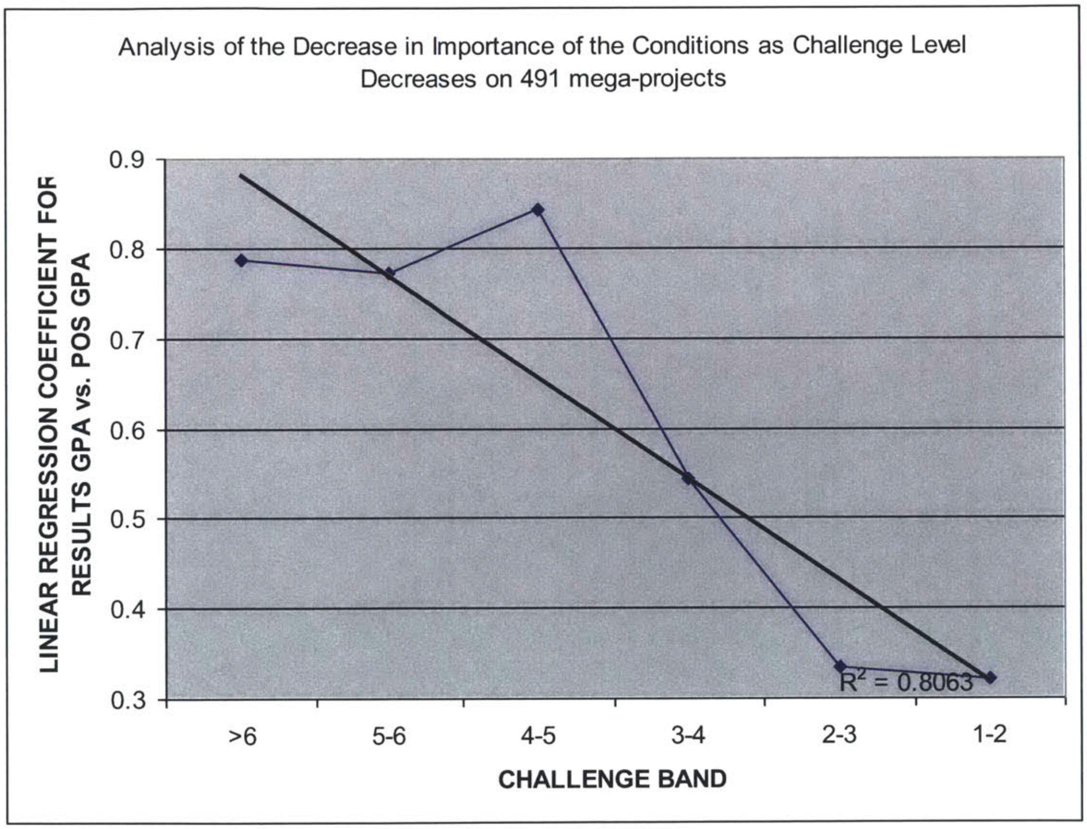


Figure B.3: R-squared value decline as a function of the challenge band level.

The R-squared value of this analysis itself is 0.8063. For the rigor level of the study conducted and the variability in the type and information of each mega-project studied, this R-squared value is sufficient to further validate our assertions of the importance of the presence and optimality of each of the 11 conditions to delivering the intended results of human endeavors as the challenge level increases.

Table B.2: List of 539 mega-projects

DOMAIN	PROJECT
Aerospace Projects	Airbus A380
Aerospace Projects	Boeing B-52 Stratofortress
Aerospace Projects	Northrop Grumman B-2 Spirit (also known as the Stealth Bomber)
Aerospace Projects	Boeing 2707 and Lockheed L-2000 supersonic aircraft projects
Aerospace Projects	Boeing 747
Aerospace Projects	Boeing 787
Aerospace Projects	Concorde
Aerospace Projects	Eurofighter Typhoon
Aerospace Projects	F-22 Raptor
Aerospace Projects	Sukhoi PAK FA/HAL FGFA
Aerospace Projects	F-35 Lightning II
Aerospace Projects	F/A-18 Hornet
Aerospace Projects	KH-11 reconnaissance satellite
Aerospace Projects	Tupolev Tu-144
Aerospace Projects	Chengdu J-20

DOMAIN	PROJECT
Airport Expansions	Beijing Capital International Airport Terminal 3 Beijing, People's Republic of China
Airport Expansions	Cape Town International Airport 2010 expansion Cape Town, South Africa
Airport Expansions	Charlotte/Douglas International Airport Construction and Expansion Charlotte, North Carolina, USA
Airport Expansions	Chhatrapati Shivaji International Airport Master expansion project Mumbai, India
Airport Expansions	Clark International Airport Terminal expansion Angeles City, Philippines
Airport Expansions	Dallas/Fort Worth International Airport Terminal A, B, C, E expansion Dallas, Texas, United States
Airport Expansions	Dubai International Airport Terminal 3 Dubai, UAE
Airport Expansions	Dublin Airport Capital development programme Dublin, Ireland
Airport Expansions	Frankfurt Airport Airport Expansion Program (AEP) Frankfurt am Main, Hesse, Germany
Airport Expansions	Haneda Airport International Terminal Tokyo, Japan
Airport Expansions	Hartsfield–Jackson Atlanta International Airport "Focus On the Future" Development Program Atlanta, Georgia, Un
Airport Expansions	Hong Kong International Airport Three-runway system Chek Lap Kok, Hong Kong
Airport Expansions	Indira Gandhi International Airport Terminal 3 New Delhi, India
Airport Expansions	John F. Kennedy International Airport Airport Redevelopment New York City, United States
Airport Expansions	London Heathrow Airport Terminal 5 London, United Kingdom
Airport Expansions	Los Angeles International Airport Bradley West program Los Angeles, United States
Airport Expansions	Madrid-Barajas Airport Terminal 4 Madrid, Spain
Airport Expansions	Munich Airport Terminal 2 Munich, Germany
Airport Expansions	O'Hare International Airport Modernization Plan Chicago, Illinois, United States
Airport Expansions	OR Tambo International Airport Terminal developments Johannesburg, South Africa
Airport Expansions	Paris-Charles de Gaulle Airport Terminal 2E Paris, France
Airport Expansions	Sheremetyevo International Airport Terminals D, E Moscow, Russia
Airport Expansions	Suvarnabhumi International Airport Terminal and runways Bangkok, Thailand

DOMAIN	PROJECT
Airport Projects	King Abdulaziz International Airport Jeddah, Saudi Arabia
Airport Projects	New Islamabad International Airport Islamabad, Pakistan
Airport Projects	Abu Dhabi International Airport Abu Dhabi, United Arab Emirates
Airport Projects	Al Maktoum International Airport Jebel Ali, UAE
Airport Projects	Amsterdam Airport Schiphol Amsterdam, Netherlands
Airport Projects	Athens International Airport Athens, Greece
Airport Projects	Barcelona International Airport Barcelona, Spain
Airport Projects	Berlin-Brandenburg International Airport Berlin, Germany
Airport Projects	Denver International Airport Denver, Colorado, United States
Airport Projects	Hong Kong International Airport Chek Lap Kok, Hong Kong
Airport Projects	Incheon International Airport Incheon, South Korea
Airport Projects	Guangzhou Baiyun International Airport Guangzhou, China
Airport Projects	Kansai International Airport Japan
Airport Projects	King Shaka International Airport Durban, South Africa
Airport Projects	Kuala Lumpur International Airport Malaysia
Airport Projects	Long Thanh International Airport Vietnam
Airport Projects	Newark Liberty International Airport Newark, New Jersey, United States
Airport Projects	Metro Manila International Airport Taguig City- Taytay, Rizal, Philippines
Airport Projects	New Lisbon Airport Lisbon, Portugal
Airport Projects	Suvarnabhumi Airport Bangkok, Thailand

DOMAIN	PROJECT
Big Science Projects	Manhattan Project, in the United States (1945)
Big Science Projects	Tevatron 2 TeV particle accelerator, in the United States (1983)
Big Science Projects	Human Genome Project, investigation to determine human genetic code (1990-Ongoing)
Big Science Projects	Superconducting Super Collider, canceled 40 TeV particle accelerator in Texas (1991–1993)
Big Science Projects	National Ignition Facility, United States nuclear fusion project (1997-Ongoing)
Big Science Projects	Large Hadron Collider 14 TeV particle accelerator, in Switzerland and France (2000-Ongoing)
Big Science Projects	ITER International nuclear fusion project, in France (2008-Ongoing)
Big Science Projects	European Extremely Large Telescope
Big Science Projects	Atacama Large Millimeter Array
Big Science Projects	Square Kilometre Array
Big Science Projects	International Linear Collider, (plan)
Big Science Projects	Compact Linear Collider, (plan)
Big Science Projects	Envisat, an Earth observation satellite of European Space Agency (2002-2012)
Big Science Projects	Thirty Meter Telescope
Big Science Projects	Large Binocular Telescope

DOMAIN	PROJECT
Bridge & Highway Projects	Arthur Ravenel Jr. Bridge, South Carolina, United States
Bridge & Highway Projects	Delaware Memorial Bridge, New Jersey, United States
Bridge & Highway Projects	Gateway Program, Vancouver, British Columbia, Canada
Bridge & Highway Projects	Hangzhou Bay Bridge, People's Republic of China
Bridge & Highway Projects	Humber Bridge, United Kingdom
Bridge & Highway Projects	Jiaozhou Bay Bridge, Qingdao, China
Bridge & Highway Projects	Akashi Kaikyo Bridge, Japan
Bridge & Highway Projects	Bandra–Worli Sea Link, Mumbai, India
Bridge & Highway Projects	Bang Na Expressway, Thailand, Bang Na Expressway
Bridge & Highway Projects	Sunda Strait Bridge, Indonesia
Bridge & Highway Projects	Rio–Antirrio bridge, Greece
Bridge & Highway Projects	Rio–Niterói bridge, Rio de Janeiro, Brazil
Bridge & Highway Projects	Egnatia Odos, Greece
Bridge & Highway Projects	Ambassador Bridge, Michigan, United States
Bridge & Highway Projects	A1 (Croatia) between Zagreb and Split, with extension being built to Dubrovnik, Croatia
Bridge & Highway Projects	A3 motorway (Romania) between Brasov and Oradea
Bridge & Highway Projects	A4 motorway (Romania) between Iasi and Târgu Mures
Bridge & Highway Projects	Bundesautobahn 20, Germany
Bridge & Highway Projects	Central Artery/Tunnel Project, more popularly known as the "Big Dig", Boston, Massachusetts, United States
Bridge & Highway Projects	George Washington Bridge, New York City, United States
Bridge & Highway Projects	National Highways Development Project, India
Bridge & Highway Projects	Manhattan Bridge, New York City, United States
Bridge & Highway Projects	Port Tunnel Dublin, Republic of Ireland
Bridge & Highway Projects	Expressway Network of the People's Republic of China
Bridge & Highway Projects	Central Texas Turnpike, Texas, United States
Bridge & Highway Projects	Fehmarn Belt Fixed Link and its connections on land, linking Denmark and Germany
Bridge & Highway Projects	Great Belt Fixed Link (Storebæltsforbindelsen), Denmark
Bridge & Highway Projects	Mackinac Bridge, United States
Bridge & Highway Projects	Pan-American Highway, Extending from North to South America.
Bridge & Highway Projects	Interstate Highway System, United States of America
Bridge & Highway Projects	Millau Viaduct, France
Bridge & Highway Projects	Lake Pontchartrain Causeway, United States
Bridge & Highway Projects	Ohio River Bridges Project, Kentucky, United States
Bridge & Highway Projects	Baluarte Bridge, Mexico
Bridge & Highway Projects	Brooklyn Bridge, New York City, United States
Bridge & Highway Projects	Verrazano-Narrows Bridge, New York City, United States
Bridge & Highway Projects	Øresund Bridge and its connections on land, like the City Tunnel (Malmö), Sweden and Denmark.
Bridge & Highway Projects	Roman road system of antiquity
Bridge & Highway Projects	Spaghetti Junction, Birmingham, United Kingdom.
Bridge & Highway Projects	Vasco da Gama Bridge, Portugal, Europe's largest bridge
Bridge & Highway Projects	Seven Mile Bridge, Florida, United States
Bridge & Highway Projects	Sunshine Skyway Bridge, Florida, United States
Bridge & Highway Projects	Karakoram Highway, Pakistan
Bridge & Highway Projects	Strait of Messina Bridge
Bridge & Highway Projects	Confederation Bridge, connecting Prince Edward Island to mainland Canada
Bridge & Highway Projects	Hong Kong-Zhuhai-Macau Bridge
Bridge & Highway Projects	Golden Quadrilateral Project, India
Bridge & Highway Projects	Golden Gate Bridge, United States
Bridge & Highway Projects	Woodrow Wilson Bridge, United States
Bridge & Highway Projects	Batangas-Mindoro Superbridge, the Philippines

DOMAIN	PROJECT
Building Projects	The front façade of the Petronas Twin Towers
Building Projects	The Time Warner Center
Building Projects	Chicago's Trump International Hotel and Tower
Building Projects	Rockefeller Center
Building Projects	Abraj Al Bait Towers, Mecca, Saudi Arabia (2011)
Building Projects	American Dream Meadowlands, New Jersey, United States
Building Projects	American Museum of Natural History, New York City, United States (1869)
Building Projects	Antilia, South Mumbai, India (2010)
Building Projects	Aon Center, Chicago, United States (1973)
Building Projects	Bank of America Corporate Center, Charlotte Global Headquarters, United States
Building Projects	Bank of America Plaza (Atlanta), United States (1992)
Building Projects	Bank of America Tower (New York City), United States (2009)
Building Projects	Berlin Hauptbahnhof (Central Station), Berlin, Germany (2006)
Building Projects	Bibliotheca Alexandrina, Egypt (2002)
Building Projects	Boeing Charleston Factory (2011)
Building Projects	Boeing Everett Factory, United States (1967)
Building Projects	British Library, London, United Kingdom (1753)
Building Projects	British Museum, London, United Kingdom (1753)
Building Projects	Buckingham Palace, London, United Kingdom (1705)
Building Projects	Burj Khalifa, Dubai, United Arab Emirates (2009)
Building Projects	Canton Tower, the tallest structure in China. (2010)
Building Projects	Chrysler Building, New York City, United States (1930)
Building Projects	Citigroup Center, New York City, United States (1977)
Building Projects	CN Tower, Toronto, Ontario, Canada (1976)
Building Projects	Cosmopolitan of Las Vegas, Nevada, United States (2010)
Building Projects	Cuatro Torres, Madrid, Spain (2009)
Building Projects	Disneyworld, Orlando, Florida, United States (1971)
Building Projects	Eiffel Tower, Paris, France (1889)
Building Projects	El Escorial, San Lorenzo de El Escorial, Spain (1557)
Building Projects	Empire State Building, New York City, United States (1931)
Building Projects	Governor Nelson A. Rockefeller Empire State Plaza, Albany, New York, United States (1978)
Building Projects	Forbidden City, Beijing, People's Republic of China (1406)
Building Projects	Gateway Arch, St. Louis, United States (1967)
Building Projects	Gran Torre Santiago, Santiago, Chile (2013?)
Building Projects	Grand Central Terminal, New York City, United States (1871)
Building Projects	Grand Egyptian Museum, Giza, Egypt (Est. 2013)
Building Projects	Great Pyramid of Giza, Giza, Egypt (2551 BC.)
Building Projects	Hungarian Parliament Building, Budapest, Hungary (1904)
Building Projects	Jakarta Tower, Jakarta, Indonesia (Est. 2011)
Building Projects	Jin Mao Tower, Shanghai, China (1999)
Building Projects	John Hancock Center, Chicago, United States (1970)
Building Projects	JPMorgan Chase Tower, Houston, United States (1982)
Building Projects	Library of Congress, Washington, D.C., United States (1897)
Building Projects	Lincoln Center, New York City, United States (1906)
Building Projects	Lopez Towers, Makati City, the Philippines
Building Projects	Louvre Museum, Paris, France (1793)
Building Projects	Marina Bay Sands hotel and casino, Singapore (2010)
Building Projects	Merchandise Mart, Chicago, United States (1930)
Building Projects	MetLife Building, New York City, United States (1963)
Building Projects	Metropolitan Museum of Art, New York City, United States (1872)
Building Projects	Millennium Dome, London, United Kingdom (2000) Now the privately held O2
Building Projects	Moscow Kremlin, Moscow, Russia (1331)
Building Projects	National Mall, Washington, D.C., United States (1791)
Building Projects	New York Public Library, New York City, United States (1911)
Building Projects	New York Times Building, New York City, United States (2007)
Building Projects	Nina Towers, Tsuen Wan, New Territories, Hong Kong (2007)
Building Projects	One World Trade Center, New York City, United States (Est. 2013)
Building Projects	Ostankino Tower, Moscow, Russia (1967)
Building Projects	Pagcor Tower, the Philippines (2016),
Building Projects	Palace of the Parliament, Bucharest, Romania (1989)
Building Projects	Palace of Versailles, Versailles, France (1682)
Building Projects	Palace of Westminster, London, United Kingdom (1860)
Building Projects	The Palazzo, Las Vegas, United States
Building Projects	The Pentagon, Arlington County, Virginia, United States (1943)
Building Projects	Petronas Towers, Kuala Lumpur, Malaysia (1998)
Building Projects	Prague Castle, Prague, Czech Republic (870)
Building Projects	Renaissance Center, Detroit, Michigan, United States (1981)
Building Projects	Rockefeller Center, New York City, United States (1939)
Building Projects	Schönbrunn Palace, Vienna, Austria (1569)
Building Projects	Shanghai Tower, Shanghai, China (Est. 2014)
Building Projects	Shanghai World Financial Center, Shanghai, China (2008)
Building Projects	Shard London Bridge, London, United Kingdom (Est. 2012)
Building Projects	Sky Tower, Auckland, New Zealand (1997)
Building Projects	Stuttgart 21, Stuttgart, Baden-Württemberg, Germany (est. 2019)
Building Projects	Sydney Opera House, Sydney, Australia (1973)
Building Projects	Taipei 101, Taipei, Taiwan, ROC (2004)
Building Projects	Tokyo Sky Tree, Tokyo, Japan (2010)
Building Projects	Tuntex Sky Tower, Kaohsiung, Taiwan (1997)
Building Projects	Texas Medical Center, Houston, United States (1945)
Building Projects	Time Warner Center, New York City, United States (2001)
Building Projects	Trump International Hotel and Tower (Chicago), United States (2009)
Building Projects	U.S. Bank Tower (Los Angeles), United States (1989)
Building Projects	United States Capitol, Washington, D.C., United States
Building Projects	Vehicle Assembly Building, Florida, United States (1966)
Building Projects	The Venetian Macao, Macau, China
Building Projects	Willis Tower (originally Sears Tower), Chicago, United States (1973)
Building Projects	Windsor Castle, Windsor, United Kingdom (Circa 1070)
Building Projects	Winter Palace, St. Petersburg, Russia (1732)
Building Projects	World Trade Center, New York City, New York, United States (1973)

DOMAIN	PROJECT
Canal Projects	All-American Canal, California, United States
Canal Projects	Arabian Canal, United Arab Emirates
Canal Projects	Central Arizona Project, Arizona, United States
Canal Projects	Sanitary and Ship Canal, Chicago, United States
Canal Projects	Danube – Black Sea Canal, Romania
Canal Projects	Erie Canal, New York, United States
Canal Projects	Göta Canal, Sweden
Canal Projects	Grand Canal, China
Canal Projects	Grand Korean Waterway, South Korea (proposed)
Canal Projects	Kiel Canal, Schleswig-Holstein, Germany
Canal Projects	Panama Canal and Panama Canal expansion project, Panama
Canal Projects	Rideau Canal, Ontario, Canada
Canal Projects	Sethu Canal, India
Canal Projects	Suez Canal, Egypt
Canal Projects	Tennessee–Tombigbee Waterway, United States
Canal Projects	Welland Canal, Ontario, Canada

DOMAIN	PROJECT
Dam and hydroelectric projects	Akosombo Dam, Ghana
Dam and hydroelectric projects	Aswan Dam, Egypt
Dam and hydroelectric projects	Atatürk Dam, Turkey
Dam and hydroelectric projects	Bakun Dam, Sarawak, Malaysia
Dam and hydroelectric projects	Belo Monte Dam, Brazil
Dam and hydroelectric projects	Bhakra Dam, India
Dam and hydroelectric projects	Cahora Bassa Dam, Mozambique
Dam and hydroelectric projects	Churchill Falls Generating Station, Canada
Dam and hydroelectric projects	Delta Works, Netherlands
Dam and hydroelectric projects	Diamer-Bhasha Dam, Pakistan (Still under construction)
Dam and hydroelectric projects	Guri Dam, Venezuela
Dam and hydroelectric projects	Grand Coulee Dam, United States
Dam and hydroelectric projects	Grande Dixence Dam, Switzerland
Dam and hydroelectric projects	Hirakud Dam, India
Dam and hydroelectric projects	Hoover Dam, United States
Dam and hydroelectric projects	Idukki Dam, Kerala, India
Dam and hydroelectric projects	Ilisu Dam, Turkey
Dam and hydroelectric projects	Inga Dam, Democratic Republic of the Congo
Dam and hydroelectric projects	Itaipu Dam, Brazil/Paraguay
Dam and hydroelectric projects	James Bay Project, Canada
Dam and hydroelectric projects	Jinping 1 Dam, China
Dam and hydroelectric projects	Kárahnjúkar Hydropower Plant, Iceland
Dam and hydroelectric projects	Manapouri Hydroelectric Power Station, New Zealand
Dam and hydroelectric projects	Manicouagan Project, Canada – see also Manic-2, Manic-3, and Manic-5
Dam and hydroelectric projects	Nagarjuna Sagar Dam, India
Dam and hydroelectric projects	Nurek Dam, Tajikistan
Dam and hydroelectric projects	Robert Moses Niagara Hydroelectric Power Station, United States
Dam and hydroelectric projects	Sayano–Shushenskaya Dam, Russia
Dam and hydroelectric projects	Snowy Mountains Scheme, Australia
Dam and hydroelectric projects	Tabqa Dam, Syria
Dam and hydroelectric projects	Tarbela Dam, Pakistan
Dam and hydroelectric projects	TaSang Dam, Burma
Dam and hydroelectric projects	Tehri Dam, India
Dam and hydroelectric projects	Tennessee Valley Authority, United States
Dam and hydroelectric projects	Three Gorges Dam, China
Dam and hydroelectric projects	Vajont Dam, Italy
Dam and hydroelectric projects	Xiaowan Dam, China
Dam and hydroelectric projects	Yacireta Dam, Argentina/Paraguay
Dam and hydroelectric projects	Deriner Dam, Turkey

DOMAIN	PROJECT
Environmentally related projects	The Deer Island PlantDeer Island Waste Water Treatment Plant, Massachusetts, United States
Environmentally related projects	Gold Coast Desalination Plant, Queensland, Australia
Environmentally related projects	Great Plains Shelterbelt, United States
Environmentally related projects	Great Plan for the Transformation of Nature, Soviet Union
Environmentally related projects	Green Wall of China, People's Republic of China
Environmentally related projects	Kurnell Desalination Plant, New South Wales, Australia
Environmentally related projects	Port Stanvac Desalination Plant, South Australia, Australia
Environmentally related projects	Seawater Greenhouse
Environmentally related projects	Sahara Forest Project

DOMAIN	PROJECT
Information Technology Projects	Cyberjaya, Malaysia
Information Technology Projects	Enabling Grids for E-science
Information Technology Projects	NHS Connecting for Health for Britain's National Health Service
Information Technology Projects	Navy/Marine Corps Intranet
Information Technology Projects	IBM System/360
Information Technology Projects	The National Broadband Network
Information Technology Projects	Gujarat International Finance Tec-City, Gujarat India
Information Technology Projects	Research Triangle Park, North Carolina, USA
Information Technology Projects	Cummings Research Park, Alabama, USA
Information Technology Projects	AADHAAR, India
Information Technology Projects	Piedmont Triad Research Park, North Carolina, USA

DOMAIN	PROJECT
International Sports Infrastructure Pro	Asian Games
International Sports Infrastructure Pro	Commonwealth Games
International Sports Infrastructure Pro	Cricket World Cup
International Sports Infrastructure Pro	FIBA Basketball World Cup
International Sports Infrastructure Pro	FIFA World Cup
International Sports Infrastructure Pro	Olympic Games
International Sports Infrastructure Pro	Rugby World Cup

DOMAIN	PROJECT
Large Space Projects	Apollo program (1960–1975)
Large Space Projects	Buran program, canceled space shuttle program (1980–1993)
Large Space Projects	Compass navigation system, system of satellite navigation by People's Republic of China (Est. 2015-2017)
Large Space Projects	Constellation program, part lives on as future Crew Escape Vehicle for ISS (2005–2010)
Large Space Projects	Orion (spacecraft), a planned spacecraft that is being built by Lockheed Martin for NASA
Large Space Projects	Galileo Navigation Satellite System, a European Union and European Space Agency global satellite navigation sys
Large Space Projects	Global Positioning System, a global satellite navigation system created by the United States Air Force (1994)
Large Space Projects	GLONASS, the Russian equivalent of GPS (1995)
Large Space Projects	Hubble Space Telescope
Large Space Projects	International Space Station, multinational space station in low Earth orbit (1998–2020)
Large Space Projects	James Webb Space Telescope (under construction)
Large Space Projects	Mir, Russian space station (1986–2001)
Large Space Projects	Soviet Moonshot, canceled moon landing program (1962–1969)
Large Space Projects	Space Shuttle program (1972–2011)
Large Space Projects	Alpha Magnetic Spectrometer, a particle physics experiment module that is mounted on the International Space St
Large Space Projects	Mars Science Laboratory
Large Space Projects	Juno (spacecraft), a NASA New Frontiers mission to the planet Jupiter (2011-)
Large Space Projects	Cassini–Huygens, a joint NASA/ESA/ASI spacecraft mission studying the planet Saturn and its many natural satelli
Large Space Projects	Galileo (spacecraft), a mission to Jupiter (1989-2003)

DOMAIN	PROJECT
Military Projects	Rock Island Arsenal, United States
Military Projects	Redstone Arsenal, United States
Military Projects	Great Wall of China, People's Republic of China
Military Projects	Maginot Line, France
Military Projects	Hadrian's Wall, United Kingdom
Military Projects	Strategic Defense Initiative, United States
Military Projects	Manhattan Project, United States
Military Projects	Željava Air Base, Croatia/Bosnia and Herzegovina
Military Projects	816 Nuclear Military Plant, China (Closed in 1984)
Military Projects	Fort Benning, United States The largest military base in the world.
Military Projects	Boden Fortress, Sweden
Military Projects	Cheyenne Mountain Directorate Base, United States
Military Projects	Nimitz class aircraft carriers, United States
Military Projects	Gerald R. Ford class aircraft carrier, United States (under construction)
Military Projects	Seawolf class submarine, United States

DOMAIN	PROJECT
Oil & Gas Projects	Gorgon gas project, Australia
Oil & Gas Projects	Athabasca oil sands, Canada, and the Keystone Pipeline
Oil & Gas Projects	Corrib Gas Project, Ireland
Oil & Gas Projects	Hibernia oil field, Canada
Oil & Gas Projects	Nord Stream, Russia
Oil & Gas Projects	South Stream, Russia
Oil & Gas Projects	Sakhalin-I, Russia
Oil & Gas Projects	Trans-Alaska Pipeline System, United States
Oil & Gas Projects	Peregrino, Brazil
Oil & Gas Projects	Jamnagar Refinery, India
Oil & Gas Projects	Nabucco pipeline, Europe (Proposed only)
Oil & Gas Projects	Troll A platform, Norway
Oil & Gas Projects	Ormen Lange pipeline, Norway, United Kingdom

DOMAIN	PROJECT
Other	Olkiluoto Nuclear Power Plant
Other	Oasis class cruise ship

DOMAIN	PROJECT
Planned Cities & Urban Renewal	Hudson Yards Redevelopment Project New York City, United States
Planned Cities & Urban Renewal	Esplanada City Center Bucharest, Romania
Planned Cities & Urban Renewal	King Teoh Economic City Saudi Arabia
Planned Cities & Urban Renewal	Dubailand Dubai, United Arab Emirates
Planned Cities & Urban Renewal	Liverpool One Liverpool, United Kingdom
Planned Cities & Urban Renewal	Putrajaya Malaysia
Planned Cities & Urban Renewal	Brasilia Brazil
Planned Cities & Urban Renewal	Battery Park City New York City, United States
Planned Cities & Urban Renewal	Brickell Key Miami, United States
Planned Cities & Urban Renewal	New Songdo City Incheon, South Korea
Planned Cities & Urban Renewal	Riverside South New York City, United States
Planned Cities & Urban Renewal	Moscow International Business Center Moscow, Russia
Planned Cities & Urban Renewal	Big City Plan Birmingham, United Kingdom
Planned Cities & Urban Renewal	Palm Islands, The World (archipelago) and Dubai Waterfront Dubai, United Arab Emirates
Planned Cities & Urban Renewal	HafenCity Hamburg, Germany
Planned Cities & Urban Renewal	New Town planning since 1950s New Territories, Hong Kong
Planned Cities & Urban Renewal	Pagcor City Metro Manila, The Philippines
Planned Cities & Urban Renewal	Movement of Kiruna Centrum Kiruna, Sweden
Planned Cities & Urban Renewal	Porto Maravilha Rio de Janeiro, Brazil
Planned Cities & Urban Renewal	Stratford City London, United Kingdom
Planned Cities & Urban Renewal	Gujarat International Finance Tec-City India
Planned Cities & Urban Renewal	Madinaty Egypt
Planned Cities & Urban Renewal	Bonifacio Global City Philippines
Planned Cities & Urban Renewal	Roppongi Hills Tokyo, Japan
Planned Cities & Urban Renewal	Eastwood City Quezon City, Philippines
Planned Cities & Urban Renewal	Okhta Center Saint Petersburg, Russia
Planned Cities & Urban Renewal	Potsdamer Platz Redevelopment Berlin, Germany
Planned Cities & Urban Renewal	Rebuilding of Christchurch New Zealand
Planned Cities & Urban Renewal	La Défense Paris, France
Planned Cities & Urban Renewal	Taguig MegaCity Taguig City-Taytay, Philippines
Planned Cities & Urban Renewal	CityCenter Las Vegas, United States
Planned Cities & Urban Renewal	Atlantic Yards New York City, United States
Planned Cities & Urban Renewal	Songdo International Business District Seoul, South Korea
Planned Cities & Urban Renewal	Navi Mumbai India

DOMAIN	PROJECT
Port Projects	Port Klang, Malaysia
Port Projects	Gwadar Port, Pakistan
Port Projects	Port of Antwerp, Belgium
Port Projects	Punta Colonet in Baja California, Mexico
Port Projects	Port Newark-Elizabeth Marine Terminal, United States
Port Projects	Port of Rotterdam, Netherlands
Port Projects	Yangshan port, China
Port Projects	Port of Hambantota, Sri Lanka
Port Projects	Port of Hamburg, Germany
Port Projects	Port of Sines, Portugal
Port Projects	Nhava Sheva, India
Port Projects	Port of Long Beach, United States
Port Projects	Port of Los Angeles, United States
Port Projects	Port of Houston, United States
Port Projects	Port of Oakland, United States
Port Projects	Port of Shanghai, China
Port Projects	Port of Tianjin, China
Port Projects	Port of Hong Kong, Hong Kong
Port Projects	Port of Miami, United States
Port Projects	Port of South Louisiana, United States
Port Projects	Port of San Diego, United States
Port Projects	Port of Singapore, Singapore
Port Projects	International Container Transshipment Terminal, Kochi, India
Port Projects	Port of London, United Kingdom
Port Projects	Port of Dover, United Kingdom

DOMAIN	PROJECT
Rail & Rapid Transit Projects	AlpTransit (NEAT), Switzerland,
Rail & Rapid Transit Projects	Amsterdam Subway, Amsterdam, Netherlands
Rail & Rapid Transit Projects	Athens Metro, Athens, Greece
Rail & Rapid Transit Projects	AVE High Speed Rail, Spain
Rail & Rapid Transit Projects	Barcelona Metro, Barcelona, Spain
Rail & Rapid Transit Projects	Bay Area Rapid Transit System, San Francisco Bay Area, California, United States
Rail & Rapid Transit Projects	Beijing Subway, Beijing, China
Rail & Rapid Transit Projects	Berlin Metro, Berlin, Germany
Rail & Rapid Transit Projects	Betuweroute, Netherlands
Rail & Rapid Transit Projects	Brussels Metro, Brussels, Belgium
Rail & Rapid Transit Projects	Bucharest Metro, Bucharest, Romania
Rail & Rapid Transit Projects	Budapest Metro, Budapest, Hungary
Rail & Rapid Transit Projects	Buenos Aires Metro, Buenos Aires, Argentina
Rail & Rapid Transit Projects	Canada Line in Vancouver, British Columbia, Canada
Rail & Rapid Transit Projects	Center City Commuter Connection, Philadelphia, Pennsylvania, United States
Rail & Rapid Transit Projects	Crossrail, London, United Kingdom
Rail & Rapid Transit Projects	Chennai Metro, Chennai, India
Rail & Rapid Transit Projects	Channel Tunnel
Rail & Rapid Transit Projects	Chicago Transit Authority, Chicago, United States
Rail & Rapid Transit Projects	Copenhagen Metro, Copenhagen, Denmark
Rail & Rapid Transit Projects	Delhi Metro, New Delhi, India
Rail & Rapid Transit Projects	Dubai Metro, Dubai, United Arab Emirates
Rail & Rapid Transit Projects	Düsseldorf Stadtbahn, Düsseldorf, Germany
Rail & Rapid Transit Projects	Eurostar Line, Europe
Rail & Rapid Transit Projects	Frankfurt U-Bahn, Frankfurt, Germany
Rail & Rapid Transit Projects	Gateway Project, New York City, United States
Rail & Rapid Transit Projects	Gautrain in Gauteng, South Africa between Johannesburg and Pretoria
Rail & Rapid Transit Projects	Greater KL MRT, Kuala Lumpur, Malaysia
Rail & Rapid Transit Projects	Guangzhou-Shenzhen-Hong Kong
Rail & Rapid Transit Projects	Guangzhou Metro, Guangzhou, China
Rail & Rapid Transit Projects	Jakarta Mass Rapid Transit, Jakarta, Indonesia
Rail & Rapid Transit Projects	Kashmir Railway, India
Rail & Rapid Transit Projects	Kozhikode Monorail, Kozhikode, India
Rail & Rapid Transit Projects	Kochi Metro, Kochi, Kerala, India
Rail & Rapid Transit Projects	Kolkata Metro, India
Rail & Rapid Transit Projects	Konkan Railway between Mangalore and Mumbai
Rail & Rapid Transit Projects	Laoag-Manila-Bicol Bullet Train, Philippines
Rail & Rapid Transit Projects	Madrid Metro, Spain
Rail & Rapid Transit Projects	Montreal Metro, Quebec, Canada
Rail & Rapid Transit Projects	Mindanao Railway System Mindanao, Philippines
Rail & Rapid Transit Projects	MTR, Hong Kong
Rail & Rapid Transit Projects	Mumbai Metro, India
Rail & Rapid Transit Projects	Haramain High Speed Rail Project, Saudi Arabia
Rail & Rapid Transit Projects	High Speed 1, Ebbsfleet International railway station, London, United Kingdom
Rail & Rapid Transit Projects	Hyderabad Metro, Hyderabad, India
Rail & Rapid Transit Projects	London Underground, United Kingdom
Rail & Rapid Transit Projects	Los Angeles Subway, United States
Rail & Rapid Transit Projects	Namma Metro, Bangalore, India
Rail & Rapid Transit Projects	Northeast Corridor, United States
Rail & Rapid Transit Projects	Marmaray in Istanbul, Turkey
Rail & Rapid Transit Projects	Massachusetts Bay Transportation Authority, Massachusetts, United States
Rail & Rapid Transit Projects	Metropolitan Atlanta Rapid Transit Authority, Atlanta, Georgia, United States
Rail & Rapid Transit Projects	Mexico City Metro, Mexico City, Mexico
Rail & Rapid Transit Projects	Miami Subway, Miami, United States
Rail & Rapid Transit Projects	Milan Metro, Milan, Italy
Rail & Rapid Transit Projects	Moscow Metro, Moscow, Russia
Rail & Rapid Transit Projects	Munich U-Bahn, Munich, Germany
Rail & Rapid Transit Projects	New York City Subway, New York City, United States
Rail & Rapid Transit Projects	Paris Métro, Paris, France
Rail & Rapid Transit Projects	Prague Metro, Prague, Czech Republic
Rail & Rapid Transit Projects	Prokop Railway Station, Belgrade, Serbia
Rail & Rapid Transit Projects	Qingzang railway in Qinghai and Tibet, China
Rail & Rapid Transit Projects	Link Light Rail, Seattle, Washington, United States
Rail & Rapid Transit Projects	Rail Axis Berlin-Palermo, European Union (Germany, Austria, Italy),
Rail & Rapid Transit Projects	Rail Axis Paris-Bratislava, European Union (France, Germany, Austria, Slovakia)
Rail & Rapid Transit Projects	Rio de Janeiro Metro, Rio de Janeiro, Brazil
Rail & Rapid Transit Projects	Saint Petersburg Metro, St. Petersburg, Russia
Rail & Rapid Transit Projects	Santiago Metro, Santiago, Chile
Rail & Rapid Transit Projects	São Paulo Metro, São Paulo, Brazil
Rail & Rapid Transit Projects	Seikan Tunnel in Japan
Rail & Rapid Transit Projects	Seoul Metropolitan Subway, Seoul, South Korea
Rail & Rapid Transit Projects	SEPTA Regional Rail, Philadelphia, United States
Rail & Rapid Transit Projects	Shanghai Metro, Shanghai, China
Rail & Rapid Transit Projects	Shiraz Metro, Shiraz, Iran
Rail & Rapid Transit Projects	Southeast High Speed Rail Corridor, Washington, DC to Jacksonville, United States
Rail & Rapid Transit Projects	Saint Petersburg Metro, Saint Petersburg, Russia
Rail & Rapid Transit Projects	Stockholm Metro, Stockholm, Sweden
Rail & Rapid Transit Projects	Singapore Metro, Singapore
Rail & Rapid Transit Projects	Taipei Metro, Taiwan
Rail & Rapid Transit Projects	Taiwan High Speed Rail, Taiwan, Republic of China
Rail & Rapid Transit Projects	Tehran Metro, Tehran, Iran
Rail & Rapid Transit Projects	Thessaloniki Metro, Thessaloniki, Greece
Rail & Rapid Transit Projects	Toronto subway and RT, Toronto, Canada
Rail & Rapid Transit Projects	Transcontinental railroads
Rail & Rapid Transit Projects	Transit City, Toronto, Canada
Rail & Rapid Transit Projects	Vancouver Subway, British Columbia, Canada
Rail & Rapid Transit Projects	Vienna U-Bahn, Vienna, Austria
Rail & Rapid Transit Projects	Warsaw Metro, Warsaw, Poland
Rail & Rapid Transit Projects	Washington Metro, Washington, D.C., United States

DOMAIN	PROJECT
Stadiums & Sports Venues	Rungrado May Day Stadium, North Korea
Stadiums & Sports Venues	Philippine Arena, Philippines
Stadiums & Sports Venues	Salt Lake Stadium, India
Stadiums & Sports Venues	Colosseum, Italy
Stadiums & Sports Venues	Charlotte Motor Speedway, Charlotte, United States
Stadiums & Sports Venues	Beijing National Stadium, Beijing, China (2008)
Stadiums & Sports Venues	Cowboys Stadium in Arlington, Texas, United States (2009)
Stadiums & Sports Venues	Indianapolis Motor Speedway, Indianapolis, United States
Stadiums & Sports Venues	Citi Field, New York City, United States
Stadiums & Sports Venues	Atlanta Motor Speedway, Atlanta, United States
Stadiums & Sports Venues	Estadio Azteca, Mexico City, Mexico
Stadiums & Sports Venues	Tokyo Racecourse, Tokyo, Japan
Stadiums & Sports Venues	MetLife Stadium in East Rutherford, New Jersey, United States (2010)
Stadiums & Sports Venues	Sky Dome, Toronto, Ontario, Canada
Stadiums & Sports Venues	Shanghai International Circuit, Shanghai, China
Stadiums & Sports Venues	Daytona International Speedway, Florida, United States
Stadiums & Sports Venues	Strahov Stadium, Prague, Czech Republic
Stadiums & Sports Venues	Circuit de la Sarthe, Le Mans, France
Stadiums & Sports Venues	SM Mall of Asia Arena, Pasay City, Metro Manila, Philippines
Stadiums & Sports Venues	Estádio do Maracanã, Rio de Janeiro, Brazil
Stadiums & Sports Venues	Stade de France, Saint-Denis, France
Stadiums & Sports Venues	Wembley Stadium, London, United Kingdom
Stadiums & Sports Venues	Camp Nou, Barcelona, Spain
Stadiums & Sports Venues	Santiago Bernabéu Stadium, Madrid, Spain
Stadiums & Sports Venues	Nou Mestalla, Valencia, Spain
Stadiums & Sports Venues	Allianz Arena, Munich, Germany
Stadiums & Sports Venues	Superdome, New Orleans, United States
Stadiums & Sports Venues	Yankee Stadium, New York City, United States

DOMAIN	PROJECT
Water infrastructure projects	Chicago River reversing its course, Chicago, Illinois, United States
Water infrastructure projects	Deep Tunnel Project, Chicago, Illinois, United States
Water infrastructure projects	Delta Works, Netherlands
Water infrastructure projects	East Bay Municipal Utility District in Oakland, California, United States
Water infrastructure projects	Elan aqueduct, 73 mile aqueduct from Elan Valley to Birmingham, United Kingdom
Water infrastructure projects	Great Manmade River, Libya
Water infrastructure projects	Gulf Intracoastal Waterway West Closure Complex, New Orleans, United States.
Water infrastructure projects	G-Cans project, Saitama Prefecture, Japan
Water infrastructure projects	MOSE Project, Venice, Italy
Water infrastructure projects	Zuiderzee Works, Netherlands
Water infrastructure projects	New York City water supply system, New York, United States
Water infrastructure projects	Saint Lawrence Seaway, United States and Canada
Water infrastructure projects	Stormwater Management and Road Tunnel (SMART), Kuala Lumpur, Malaysia
Water infrastructure projects	Snowy Mountains Scheme in New South Wales/Victoria, Australia
Water infrastructure projects	South–North Water Transfer Project, People's Republic of China
Water infrastructure projects	State Water Project, California, United States
Water infrastructure projects	Thames Tideway Scheme, London, United Kingdom
Water infrastructure projects	Thames Barrier, London, United Kingdom
Water infrastructure projects	Southeastern Anatolia Project, Turkey
Water infrastructure projects	Saint Petersburg Dam, Russia

APPENDIX C: EXAMPLES OF CENTERS OF RESEARCH & INNOVATION THAT NEED TO BE LINKED TOGETHER

Department of Molecular Biotechnology, U. of Washington SEATTLE, WA

Kleiner Perkins Caufield & Byers MENLO PARK, CA

Departments of Electrical Engineering and Computer Science, Stanford PALO ALTO, CA

IDEO PALO ALTO, CA

Xerox PARC PALO ALTO, CA

Pixar POINT RICHMOND, CA

Disney Imagineers GLENDALE, CA

CalTech PASADENA, CA

Gehry and Associates SANTA MONICA, CA

Center for Evolutionary Psychology U. C. SANTA BARBARA

Santa Fe Institute SANTA FE

National Center for Atmospheric Research BOULDER, CO

Rocky Mountain Institute SNOWMASS, CO

Center for Twin and Adoption Research UNIVERSITY OF MINNESOTA, MINNEAPOLIS

Washington University/ Monsanto ST. LOUIS, MO

National Center for Supercomputing Applications UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Carnegie Mellon PITTSBURGH, PA

Defense Advanced Research Projects Agency ARLINGTON, VA

Entomology Labs GAINESVILLE, FL

Immigration and Naturalization Service WASHINGTON, D. C.

Johns Hopkins BALTIMORE

Financial Engineering program, NYU Stern School of Business NEW YORK

Watson Labs YORKTOWN HEIGHTS, NY

Center for International Development HARVARD, CAMBRIDGE, MA

Whitehead Institute CAMBRIDGE, MA

MIT Media Lab, Computer Science Lab, Artificial Intelligence Lab CAMBRIDGE, MA

BIBLIOGRAPHY

Altshuler, A., and Luberoff, D. (2003), *Mega-Projects: The Changing Politics of Urban Public Investment*, Brookings Institution Press, Washington, DC.

Anderson, L., Anderson, W., Krathwohl, D., and Bloom, B. S. (2001), *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*, Longman, New York.

Ansel, H.C., Loyd, A.V., and Popovich, N.G. (2005), *Ansel's Pharmaceutical Dosage Forms and Drug Delivery Systems 8th Edition*, Lippencott, Williams & Wilkins, New York, NY.

Argyris, C. (1993), *Knowledge for Action: A Guide to Overcoming Barriers to Organizational Change*, Jossey-Bass, San Francisco, CA.

Aust, A. (1993), "The Procedure and Practice of the Security Council Today", *The Development of the Role of the Security Council,* Rene-Jean Dupuy (ed.)

Ball, P.B. (2011), "Crisis Response: The New History," *Nature*, Volume 480, pp. 447–448.

Barabasi, A-L. (2002), *Linked: The New Science of Networks*, Perseus, New York, NY.

Barabasi, A-L, and Albert, R. (2002), "Emergence of Scaling in Random Networks," *Science*, 286:509-512.

Bauman, R., Jackson, P., and Lawrence, J. (1997), *From Promise to Performance, A Journey of Transformation at SmithKline Beecham*, HBS Press, Boston, MA.

Bazerman, M. (1998), *Judgment in Managerial Decision Making*, 4th edition, John Wiley & Sons, New York, NY.

Beinhocker, E.D. (2006), "The Origin of Wealth: Evolution, Complexity, and the Radical Remaking of Economics," Harvard Business School, Boston, MA.

Belliveau, P., Griffin, A., and Somermeyer, S. (2004), *The PDMA Toolbook 2 for New Product Development*, Wiley, Hoboken, NJ.

Benson, R.S., and MacCabe, D.J. (2004), "From Good Manufacturing Practices to Good Manufacturing Performance," *Pharmaceutical Engineering*, July/August, volume 24, No. 4, pp. 26-34.

Biegler, L.T., Ignacio E.G., and Westerberg, A.W. (1997), *Systematic Methods of Chemical Process Design*, Prentice Hall PTR.

Bimber, B. (1998), "Three Faces of Technological Determinism," in Does Technology Drive History? The Dilemma of Technological Determinism, MIT Press, Cambridge, MA.

Blenko, M. W., Mankins, M. C., and Rogers, P. (June 2010), "The Decision Driven Organization," *Harvard Business Review*, Cambridge, MA.

Bouchard, J. (2010), "Human Errors, How and Why they happen? How to prevent them?" Merck/MSD internal presentation, Merck & Company, Inc., Whitehouse Station, NJ.

Buelow, S.J., Worl, L.A., Harradine, D., (1998), "*Hydrothermal Processing of Radioactive Combustible Waste*", American Institute of Chemical Engineers, New York, NY.

Chang, C.M. (2010), *Service Systems Management and Engineering*, John Wiley & Sons, Hoboken, NJ.

Chapman, C. (2011), "50 Great Examples of Data Visualization," *webdesigner Depot*, WDD, Vancouver CA.

Chokshi, R. (2004), "Evaluation of hot-melt extrusion technology to improve dissolution rates of poorly water soluble drugs," Doctoral dissertation, University of Rhode Island, Kingston, RI.

Choudhury, A.K. (1984), *The Independence of East Bengal*, Baishakhi Mudrayan, Dhaka, Bangladesh.

Chowdhury, A. K., and Erdenebileg, S. (2006), *Geography against Development: A Case for Landlocked Developing Countries*, United Nations, New York, NY.

Chowdhury, A.K. (2010), "Women at the Center of Peace: UN Security Resolution 1325", *Women and War Conference,* Proceedings of the Conference on Women and War.

Chowdhury, A. (1997), "Hydrothermal Processing of Hanford Tank Wastes," Graduate Thesis, University of Rochester, Rochester, NY/Los Alamos National Laboratory, Los Alamos, NM.

Chowdhury, A. (2009), "Technology Strategy Papers 15.965 #1-4, Pharmaceutical Manufacturing Technology Platforms," Individual Paper Assignments for partial fulfillment of requirements of Fellowship, System Design & Management, Massachusetts Institute of Technology, Cambridge, MA.

Christensen, C. (1992), “Exploring the Limits of the Technology S-Curve - Part I: Architectural Technologies”, *Production and Operations Management*, pp. 358-366.

Christensen, C.M., and Sundahl, D. (2001), "Getting the Innovation Job Done: Matching the Right New Product With the Right Market," Harvard Business School working paper available from the author, Harvard University, Cambridge, MA.

Christensen, C. (2003), "Why Hard-Nosed Executives Should Care About Management Theory," *Harvard Business Review*, Cambridge, MA.

Christensen, C. M., Grossman, J. H., and Hwang, J. (2009), *The Innovator's Prescription: A Disruptive Solution for Health Care*, McGraw-Hill, New York, NY.

Clark, K., and Wheelwright, S. C. (1992), "Organizing and Leading "Heavyweight" Development Teams" *California Management Review*, (34): pp. 201-215.

Collings, M. (2009), *What is Beauty?,* BBC Programming.

Cohen, S. G., and Ledford, G. E. (1994), "The Effectiveness of Self-Managing Teams: A Quasi-Experiment," *Human Relations*, 47(1): pp. 13-43.

Conner, D.R. (1998), *Leading at the Edge of Chaos: How to Create the Nimble Organization*, John Wiley, New York, NY.

Conner, D.R. (2006), *Managing at the Speed of Change,* Villard, New York, NY.

Cooper, R. G., Edgett, S. J., and Kleinschmidt, E. K. (1998), *Portfolio Management for New Products*, Addison-Wesley, Reading, MA.

Costandi, M. (2008), "Beauty and the Brain," *SEED Magazine*, Seed Media Group.

Cournoyer, et al. (2003), *Growth Initiatives Technology Framework*, Eastman Kodak Company, Rochester, NY.

Crawley, E. (2010), "Tutorial on Fundamental Processes – ESD.34," MIT SDM program lectures.

Crawley, E., de Weck, O., Eppinger, S., Magee, C., Moses, J., Seering, W., Schindall, J., Wallace, D., and Whitney, D. (2004), "The Influence of Architecture in Engineering Systems," MIT Engineering Systems Division Monograph.

Creveling, C.M. (1997), *Tolerance Design: A Handbook for Developing Optimal Specifications*, Addison-Wesley, Reading, MA.

Cross, R., and Thomas, R.J. (2009), *Driving Results through Social Networks: How Top Organizations Leverage Networks for Performance and Growth*, John Wiley & Sons, New York, NY.

Cross, R., Singer, J., Zehner, D., and Vossen, D. (2009), "Global Pharmaceutical Commercialization Organizational Network Analysis Final Report," Merck Internal Document, Merck & Company, Inc., Whitehouse Station, NJ.

Csikszentmihalyi, M. (1990), *Flow: The Psychology of Optimal Experience,* Harper & Row, New York, NY.

Csikszentmihalyi, M. (1996), *Creativity: Flow and the Psychology of Discovery and Invention*, Harper Collins Publishers, New York, NY.

Dawkins, R. (2006), *The Selfish Gene,* Oxford Univ. Press, Oxford, UK

Davies, M.A.M. (2008), "15.965 Technology & Strategy – Iridium and Technologies Lecture Notes," MIT-SDM Lectures, Massachusetts Institute of Technology, Cambridge, MA.

Davies, M.A.M. (2009), "15.965 Technology & Strategy – Life Cycles and Transitions," MIT-SDM Lectures, Massachusetts Institute of Technology, Cambridge, MA.

Davies, M.A.M., (2009b), "15.965 Technology & Strategy – Business Ecosystems, Value Capture, Value Creation." MIT-SDM Lectures, Massachusetts Institute of Technology, Cambridge, MA.

Davies, M.A.M. (2009c), "15.965 Technology & Strategy – A Recap on Technological Innovation, and Its Co-evolution with Demand Opportunity, " *MIT-SDM Lectures*, Massachusetts Institute of Technology, Cambridge, MA.

Drakulich, A. (2008), "Trends in FDA Enforcement Actions," *Pharmaceutical Technology*, Volume. 32, Issue 11, p. 30.

Eickhoff, M. et al. (2007), "Decision Tree for Insoluble Compounds," Merck Internal Document, Merck & Company, Inc., Whitehouse Station, NJ.

Eisenhardt, K. M. (1989), "Making Fast Strategic Decisions in High-Velocity Environments," *Academy of Management Journal*, (12): pp. 543-576.

Ericsson, K. A. (2006), "The Influence of Experience and Deliberate Practice on the Development of Superior Expert Performance," in Cambridge Handbook of Expertise and Expert Performance, editors: K. A. Ericsson, N. Charness, P. Feltovich, and R. R. Hoffman, pp. 685-706, Cambridge University Press, Cambridge, UK.

Feldman, D.P., and Crutchfield, J. (1998), "A Survey of Complexity Measures," Working Paper. Santa Fe Institute.

Ferris, T. (2011), "The Big Idea: How Breakthroughs of the Past Shape the Future," *National Geographic*, Washington, D.C.

Flyvbjerg, B., Bruzelius, N., and Rothengatter, W. (2003), *Megaprojects and Risk: An Anatomy of Ambition*, Cambridge University Press, Cambridge, UK.

Freeman, C., and Soete, L. (1997), *The Economics Industrial Innovation*, Routledge, Oxon, UK.

Forrester, J. W. 1961. *Industrial Dynamics*. Cambridge MA: Productivity Press.

Forrester, J. W. 1973. *World Dynamics*. (2 ed.). Cambridge MA: Productivity Press.

Gardner, H., and Laskin, E. (1996), *Leading Minds: An Anatomy of Leadership*. BasicBooks, New York, NY.

Gell-Mann, M., and Lloyd, S. (2004), "Effective Complexity. In Nonextensive Entropy-Interdisciplinary Applications," pp. 387-398.*Oxford University Press*, New York, NY.

Giffin, M. (2007), "Change Propagation in Large Technical Systems," S. M. Thesis, System Design & Management, Massachusetts Institute of Technology, Cambridge, MA.

Gilbert, D. T. (2006), *Stumbling on Happiness*, A.A. Knopf, New York, NY.

Gladwell, M. (2000), *The Tipping Point: How Little Things Can Make a Big Difference*, Little, Brown, Boston, MA.

Greiner, L., and Poufelt, F. (2005), "*The Handbook of Management Consulting - The Contemporary Consultant: Insights from World Experts*," Thompson/South-Western, Mason, OH.

Guimerua, R., and Amaral, N. L. A. (2006), "Functional Cartography of Complex Metabolic Networks," *Nature*, 433:895-900.

Hacherl, J., and Stubenrauch, J. (2006), "Product Definition Part A – Business Process Update," Merck/MSD internal document, Merck & Company, Inc., Whitehouse Station, NJ.

Hale, P. (2010), "Requirements Engineering, Systems Engineering Lecture," MIT-SDM Lectures, Massachusetts Institute of Technology, Cambridge, MA.

Hambrick, D. (1998), "Corporate Coherence and the Top Management Team," in Navigating Change, editors: D. Hambrick, D. Nadler, and M. Tushman, 123-140. HBS Press, Boston, MA.

Hambrick, D. (2009), "The Definition of Strategy," *Merck Business Leadership Program*, Whitehouse Station, NJ.

Harrison, E.F. (1996), *The Managerial Decision-Making Process*, (4th Ed.). Boston: Houghton-Mifflin, New York, NY.

Hayes, R.H., and Wheelwright, S.C. (2004), *Link Manufacturing Process and Product Life Cycles,* Free Press, London, UK.

Hayes, R., Wheelwright, S., and Clark, K. (1988), *Dynamic Manufacturing: Creating the Learning Organization*, Free Press, London, UK.

Henderson, R., and Clark, K. (1990), "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms", *Administrative Science Quarterly*, pp. 9-30.

Hersey, P., and Blanchard, K. (1969), "Life Cycle Theory of Leadership," *Training and Development Journal*, 23(2): pp. 26-34.

Heylighen, F. (1994), "Memetic Selection Criteria," http:// pespmc1. vub.ac. be/ MEMSELC.html.

Heylighen, F. (1999), Principia Cybernetica Web (Principia Cybernetica, Brussels), http://cleamc1 1.vub.ac.be.

Hickey, A.J., and Ganderton, D. (2001), *Pharmaceutical Process Engineering*, Marcel Dekker, Inc., New York, NY.

Hobbs, M., and Chowdhury, A. (2007), "Decision Making for Integrated Development, Execution and Supply Council," *IDEAS-C documentation,* Merck Internal Document, Merck & Company, Inc., Whitehouse Station, NJ.

Hudson Institute Center for Science in Public Policy. (2004), *A Review of Pharmaceutical Company Contributions: HIV/AIDS, Tuberculosis, Malaria and Other Infectious Diseases,* Washington D.C.

IBM Business Consulting Services. (2005a), "The Metamorphosis of Manufacturing: From Art to Science."

IBM Business Consulting Services. (2005b), "Transforming Industrialization: A new Paradigm for Pharmaceutical Development."

Ikeda, C., et al. (2009), "Technology Platform Process Map," Merck Internal Document, Merck & Company, Inc., Whitehouse Station, NJ.

Jacoby, D. (2010), "Apprenticeship in the United States," http://ww.eh.net.

Janis, I.L. (1982), *Victims of Groupthink*, 2nd Edition, Houghton Mifflin, Boston, MA.

Janis, I.L., and Mann, L. (1977), *Decision Making: A Psychological Analysis of Conflict, Choice, and Commitment*, Free Press, New York, NY.

Johnson, D.W., and Johnson, F.P. (2000), *Joining Together: Group Theory and Group Skills*, 7th Edition, Allyn and Bacon, Boston, MA.

Kahneman, D. (2011), *Thinking, Fast and Slow*, Farrar, Straus and Giroux, New York, NY.

Kates, A., and Galbraith, J. (2007), *Designing your Organization: Using the STAR Model to Solve 5 Critical Design Challenges*, Jossey-Bass, San Francisco, CA.

Katz, R. (1997), *The Human Side of Managing Technological Innovation: A Collection of Readings*, Oxford University Press, New York, NY.

Katzenbach, J.R., and Smith, D.K. (1992), *Wisdom of Teams*, Harvard Business School Press, Boston, MA.

Kelly, C. (2007), *The Manhattan Project: The Birth of the Atomic Bomb in the Words of Its Creators, Eyewitnesses, and Historians.* Black Dog & Leventhal, New York, NY.

Kelly, K. (1995), *Out of Control: The New Biology of Machines, Social Systems, and the Economic World. Reading*, Addison-Wesley, Boson, MA.

Kim, W. C., and Mauborgne, R. (1997), "Fair Process: Managing in the Knowledge Economy," *Harvard Business Review*, 75(4): pp. 65-75.

Kukura, J. (2012), "Strategic Manufacturing Technology Management in the Pharmaceutical Industry," Cornell University Lecture, Policy Analysis and Management in the Pharmaceutical Industry. Ithaca, NY.

Kukura, J., Starbuck, C., and Chowdhury, A., et al. (2007), "Merck Commercialization Technical Forum White Paper on a Framework and Guidance for Distinguishing Core and Non - Core Technologies," Merck Internal Document, Merck & Company, Inc., Whitehouse Station, NJ.

Larson, J. R., Foster-Fishman, P. G., and Keys, C. B. (1994), "Discussion of Shared and Unshared Information in Decision-Making Groups" *Journal of Personality and Social Psychology*, 67(3): pp. 446-461.

Leonard, D., and Rayport, J. (1997), "Spark Innovation Through Empathic Design," *Harvard Business Review*, Harvard Business School Publishing Corporation, Boston, MA.

Los Alamos National Laboratory, LANL (2008), "*Building the Future of Los Alamos: The Premier National Security Science Laboratory.*" Los Alamos, NM

Makumbe, P.O. (2008), " Globally Distributed Product Development: Role of Complexity in the What, Where and How". Submitted to the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Engineering Systems, Massachusetts Institute of Technology, Cambridge, MA.

Maier, M., and Rechtin, E. (2000), *The Art of Systems Architecting*, CRC Press, New York, NY.

Mannix, E. (1993), "Coalitions in the Organizational Context: The Effects of Power Balance on Coalition Formation in Small Groups," Organizational Behavior and Human Decision Processes, (55): pp. 1-22.

McGrath, M. E. (2001), *Product Strategy for High Technology Companies*, McGraw-Hill, New York, NY.

Meadows, D.H., Meadows, D.L., Randers, J. and Behrens III, W.W. (1972), http://www.smithsonianmag.com/science-nature/Looking-Back-on-the-Limits-of-Growth.html#ixzz1uxV1hF6u.

Meadows, D. H., D. L. Meadows, J. Randers, & W. W. Behrens III. (1972), *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. Universe Books, New York, NY.

Meadows, D. L., & D. H. Meadows, eds. (1974), *Toward Global Equilibrium: Collected Papers.* Productivity Press, Cambridge MA.

Meadows, D. H., D. L. Meadows & J. Randers. (1992) *Beyond the Limits: Confronting Global Collapse, Envisioning A Sustainable Future.* Chelsea Green, Post Mills, VT.

Merck Human Resources. (2008), "Organizational Design Accelerator Toolkit," Merck/MSD internal presentation, Merck & Company, Inc., Whitehouse Station, NJ.

Miller, J. (2007), "Functional Versus Full-Service Outsourcing Models," *Pharmaceutical Technology*, Vol. 31, Issue 5, pp. 76-78.

Miller, J. (2008a), "Planning for the Last War," *Preview Pharmaceutical Technology*, Vol. 32, Issue 5, pp. 102-104.

Miller, J. (2008b), "Weak Link in the Supply Chain," *Pharmaceutical Technology*, Vol. 32, Issue 4, pp. 86-88.

Mintzberg, H. (1983), *Power In and Around Organizations*, Prentice-Hall, Englewood Cliffs, NJ.

Mitchell, M. (2006), "Complex Systems: Network Thinking," Working Paper, Santa Fe Institute, Santa Fe, New Mexico.

Mollick, E. (2009), "15.969 - A Special Seminar in Management: User-Centered Innovation in the Internet Age – Using Fun to Create Value" MIT-SDM Lectures, Massachusetts Institute of Technology, Cambridge, MA.

Montoya, M. (2010), " On Developing Business Architectures: A Multi-Framework Evaluation of an Early-Stage Enterprise," S. M. Thesis, System Design & Management, Massachusetts Institute of Technology, Cambridge, MA.

Moore, G.A. (2002), "Crossing the Chasm: Marketing and Selling Disruptive Products to Mainstream Customers," Harper Business Essentials.

Moreton, R.C. (2007), "Manufacturing One Trend at a Time," *Pharmaceutical Technology*, Volume. 31, Issue 10, p218-218.

Moses, J. (2004), "Foundational Issues in Engineering Systems: A Framing Paper," MIT Engineering Systems Symposium, Massachusetts Institute of Technology, Cambridge, MA.

Murray, A., et al. (2008), "Harbingers Of Change," *Preview Pharmaceutical Executive*, August 2008, Volume 29, Issue 8, pp. 52-62.

Murray, A. (1989), "Top Management Group Heterogeneity and Firm Performance," *Strategic Management Journal*, (10): pp. 125-141.

Nelson, R.R. (2003), "Physical and Social Technologies and Their Evolution," Columbia University working paper available from the author, Columbia University, New York, NY.

Nightingale, D. (2010), "Enterprise Process Management," MIT-SDM Lectures, Massachusetts Institute of Technology, Cambridge, MA.

NOQ. (2010), NOQ's Journal. http://noq-journal.blogspot.com.

Parikh, D. (1997), *Handbook of Pharmaceutical Granulation Technology,* Marcel Dekker, New York, NY.

Peters, R.C. (2008), "What Lies Ahead?," *Drug Discovery & Development*, Volume 11, Issue 11, pp. 16-21.

Phaal, R., Farrukh, C. J. P., and Probert, D. R. (2004), "Technology Roadmapping - A Planning Framework for Evolution and Revolution," *Technological Forecasting and Social Change*, 71, pp. 526, ISSN 0040-1625.

Phaal, R., Farrukh, C. J. P., and Probert, D. R. (2004), "A Framework for Supporting the Management of Technological Knowledge." *International Journal of Technology Management*, 27, pp. 1-15, ISSN 0267-5730.

Phaal, R., Farrukh, C., Mitchell, R., and Probert, D. (2003), "Starting-Up Roadmapping Fast," *IEEE Engineering Management Review*, 31, pp. 54-60, ISSN 0360-8581.

Phaal, R. (2003), "Strategic roadmapping: linking technology resources to business objectives." International Journal of Technology Management, 26, ISSN 0267-5730.

Peters, R.C. (2008), "What Lies Ahead?" *Drug Discovery & Development*, Volume 11, Issue 11, pp. 16-21.

Podsakoff, P.M., MacKenzie, S.B., Podsakoff, N.P, and Bachrach, D.G. (2008), "Scholarly Influence in the Field of Management: A Bibliometric Analysis of the Determinants of University and Author Impact in the Management Literature in the Past Quarter Century," *Journal of Management*, Volume 34, Number 4, pp. 641-720.

Preview Drug Discovery & Development, (2008), "Emerging Trends in Cell Biology Research" Volume 11, Issue 11, pp. 43-43.

Quinn, R.E. (1988), *Beyond Rational Management: Mastering the Paradoxes and Competing Demands of High Performance*, Jossey-Bass, San Francisco, CA.

Ramachandran, V. S. (2011), *The Tell-tale Brain: A Neuroscientist's Quest for What Makes Us Human*, W.W. Norton, New York, NY.

Ramage, J. D., and Bean, J. C. (1998), *Writing Arguments*, 4th Edition, Needham Heights, pp. 81-82, Allyn & Bacon, Boston, MA.

Ravasz, E., Somera, A.L., Mongru, D.A., Oltvai, Z.N., and Barabási1, A-L. (2002), "Hierarchical Organization of Modularity in Metabolic Networks," *Science*.

Reisner, Y. (2010), *Architecture and Beauty: Conversations with Architects about a Troubled Relationship,* John Wiley & Sons, New York, NY.

Rhodes, D. (2009), "Systems Engineering & Tradespaces," Engineering Systems Division Lectures, Massachusetts Institute of Technology, Cambridge, MA.

Rhodes, R. (1986). *The Making of the Atomic Bomb*. Simon & Schuster, New York, NY.

Rhodes, R. (2010). *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World without Nuclear Weapons*.: Alfred A. Knopf, New York, NY.

Robertson, S. et al. (2007), "*Defining Final Market Images to Meet Global Marketing Needs, Including Japan,*" Merck/MSD internal presentation, Merck & Company, Inc., Whitehouse Station, NJ.

Rogers, E.M. (1962), *Diffusion of Innovations,* Simon & Schuster, New York, NY.

Russell, B. (1919), *The Study of Mathematics*, Longman, London, UK.

Sachs, J. (2008), *Common Wealth: Economics for a Crowded Planet,* Penguin, New York, NY.

Sahinidis, N.V., Grossman, I.E., Fornari, R.E., and Chatharthi, M. (1989), "Optimization Model for Long Range Planning in the Chemical Industry," *Computers & Chemical Engineering.*

Scherer, F. M. (2007), "Uncertainty and Choice: the Challenges of Pharmaceutical Efficacy, Safety, and Cost," *Managerial & Decision Economics*, Volume 28, Issue 4/5, pp. 267-283.

Scholtes, P.R., Joiner, B.L., Streibel, B.J., and Mann, D. (1996), *The Team Handbook*, 2nd Edition, Oriel, Inc.

Schrage, M. (1999), "The Red-Hot Centers of Genius," *Esquire Magazine,* November Issue.

Senge, P., (2006), *The Fifth Discipline: The Art & Practice of the Learning Organization,* Currency, Doubleday, New York, NY.

Shankar, P. (2008), "Cost-Cutting Done, Pharma Heads Weigh New Challenges," Previous Volume 21, Issue 49, pp. 15-15.

Sinek, S. (2009), *Start with Why: How Great Leaders Inspire Everyone to Take Action.* Portfolio, New York, NY.

Skinner, B.F. (1974), *About Behaviorism*, New York Press, New York, NY.

Stacey, P. (2011), http://edtechfrontier.com/

Steiner, I.D. (1972), *Group Process and Productivity*, Academic Press, New York, NY.

Sterman, J. (2000), *Business Dynamics*, Irwin/McGraw Hill, Boston, MA.

Suarez, F. (2004), "Battles for Technological Dominance: An Integrative Framework," *Research Policy*, Volume 33, pp. 271-286.

Suarez, F., and Lanzolla, G. (2005), "The Half-Truth of First-Mover Advantage," *Harvard Business Review*, pp. 121-127.

Talmon, S. (2003), "The Statements of the President of the Security Council", *Chinese Journal of International Law*. Oxford University Press.

Thomke, S., and von Hippel, Eric. (2002), "Customers as Innovators: A New Way to Create Value," *Harvard Business Review*, Harvard Business School Publishing Corporation, Boston, MA.

Tripsas, M., and Gavetti, G. (2000), "Capabilities, Cognition and Inertia: Evidence from Digital Imaging," *Strategic Management Journal*, pp. 1147-1161.

UN Security Council (2012), "Hindsight: Security Council Press Statement,", *Security Council Reports,* New York, NY.

van Arnum, P. (2007), "Investing in High-Potency Manufacturing," *Pharmaceutical Technology*, Volume 31, Issue 11, pp. 54-58.

Vereshchagin, N. K., and Vitanyi, P. M. B. (2004), "Kolmogorov's Structure Function and Model Selection," IEEE Trans. Inform. Theory, 50/12, 3265-3290.

von Hippel, E. (2005), *Democratizing Innovation*, The MIT Press, Cambridge, MA.

Wally, W. (2009), *Lean, Six Sigma, Root Cause Analysis, Human Error, and Corrective Action - What does it all mean?* Ceptara Publishing.

Wikipedia contributors (2012), "Megaproject," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Megaproject&oldid=491717060 (accessed May 16, 2012).

Womack, J., and Jones, D. (2007), *Lean Solutions*, Simon & Schuster, London, UK.

IMAGES

All images have been used under the rightful copyright laws and fair practices of legal reproduction. All images fell under either the Creative Commons Attribute Share-Alike or GNU Free Documentation License or under the Fair Use Laws of the United States.

Section 4:

1. http://www.favim.com
2. http://2020visions.wordpress.com/

Section 5:

1. Rural Electrification: Wikipedia contributors, "Rural Utilities Service," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Rural_Utilities_Service&oldid=488765862 (accessed May 10, 2012).
2. Automobiles: Wikipedia contributors, "Assembly line," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Assembly_line&oldid=491594459 (accessed May 10, 2012).
3. Airplanes: Wikipedia contributors, "National Advisory Committee for Aeronautics," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=National_Advisory_Committee_for_Aeronautics&oldid=490679901 (accessed May 10, 2012).
4. Water Supply & Distribution: Wikipedia contributors, "William Mulholland," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=William_Mulholland&oldid=459266357 (accessed May 10, 2012).
5. Electronics: Wikipedia contributors, "Integrated circuit," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Integrated_circuit&oldid=491139221 (accessed May 10, 2012).
6. Radio & Television: Wikipedia contributors, "RCA," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=RCA&oldid=491309244 (accessed May 10, 2012).
7. Agricultural Mechanization: Wikipedia contributors, "Fordson," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Fordson&oldid=16872968 (accessed May 10, 2012)
8. Computers: Wikipedia contributors, "Semi-Automatic Ground Environment," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Semi-Automatic_Ground_Environment&oldid=479593548 (accessed May 10, 2012).

9. Highways: Wikipedia contributors, "Interstate Highway System," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Interstate_Highway_System&oldid=491675555 (accessed May 10, 2012).
10. Spacecraft: Wikipedia contributors, "Apollo (spacecraft)," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Apollo_(spacecraft)&oldid=488836897 (accessed May 10, 2012).
11. Imaging: Wikipedia contributors, "Brownie (camera)," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Brownie_(camera)&oldid=490925133 (accessed May 10, 2012).
12. Household Appliances: Wikipedia contributors, "Home appliance," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Home_appliance&oldid=484339847 (accessed May 10, 2012).
13. Health Technologies: Wikipedia contributors, "Human Genome Project," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Human_Genome_Project&oldid=491357645 (accessed May 11, 2012).
14. Health Technologies: Wikipedia contributors, "Vaccine," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Vaccine&oldid=491400773 (accessed May 11, 2012).
15. Fiber Optics: Wikipedia contributors, "Fiber Optics," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Fiber_Optics&oldid=30766002 (accessed May 16, 2012).
16. Manhattan Project: Wikipedia contributors, "Manhattan Project," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Manhattan_Project&oldid=491575552 (accessed May 16, 2012).
17. Wikipedia contributors, "Einstein–Szilárd letter," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Einstein%E2%80%93Szil%C3%A1rd_letter&oldid=475793088 (accessed May 18, 2012).

ABOUT THE AUTHOR

Anando A. Chowdhury leads the Organizational Strategy, Management and Operations function for Merck's Global Science, Technology and Commercialization (GSTC) organization. His team focuses on directly leading or enabling strategic or transformational initiatives, delivering project management excellence to critical GSTC activities, enabling GSTC to be a high performance organization especially in the area of capability development and providing enterprise-level business process management and structure. Throughout his time at Merck, he has been led or supported many company and manufacturing-wide transformational initiatives.

Prior to Merck, Anando has worked in areas as broad as product development, process engineering, equipment design, installation and commissioning, fundamental manaufacturing research & development, information systems and technologies, new business ventures, applied management sciences and as a operations manager for a start-up business. Anando worked as a Commercialization Manager, Product Accelerator for Eastman Kodak Company's New Business Ventures & Growth Initiatives Group. During this period he was able to work with a myriad of other industries through cooperative, technology-based business development partnerships; from textiles, automotive, aerospace, info-imaging and food/household goods.

Prior to this new business venture work, he held the position of Manager in Kodak's Global Manufacturing Technology Organization, responsible for business operations as well as the manufacturing technology strategy and initiatives for the organization. He also operated Kodak's Manufacturing Rotation Program. As a chemical engineer, team leader and new manufacturing technology commissioning manager with Kodak's International Group he was stationed in Peabody, Massachusetts, Windsor, Colorado, Eglinton, Canada, Chalon-sur-Saone, France, Harrow, England, and Sao Jose dos Campos, Brazil.

Prior to Kodak, Anando researched hydrothermal processing techniques at the Los Alamos National Laboratory, was an R&D product development engineer working on novel charged-plasma sterilization devices for hospital and professional use at MDT Biologics, Getinge USA, Inc., was an information systems and data mining specialist for United Nations Children's Fund and studied leukocyte adhesion in Biophysics group of the Strong Memorial Hospital system.

He holds a B.S. and M.S. in Chemical Engineering and Biomedical Engineering from the University of Rochester. His graduate work in chemical engineering dealt with the use of hydrothermal processing and supercritical fluid phenomena for the remediation of nuclear waste at the Hanford, Washington being used at the Los Alamos National Laboratory.

He is a Six Sigma Black Belt and a graduate of Merck's Business Leadership Program organized through Duke University's Executive Education program. He is the Merck Liaison and Fellow of the System Design and Management program of MIT's School of Engineering and Sloan School of Management. He is a graduate of ASIJ in Chofu-shi, Tokyo, Japan.. A global citizen, he has lived in around the world growing up. He is married with two children and lives in Plainsboro, NJ.

His ongoing research interests are in biological and pharmaceutical product and process development, complexity theory, sustainability, organizational design & development, individual and mass human behavioral sciences and technology policy and regulations.

This page is left intentionally blank.

This page is left intentionally blank.