Accelerated Radical Innovation (ARI) Methodology Validation

John P. Dismukes[1], Lawrence K. Miller[1], John A. Bers[2], Jai A. Sekhar[3], Alec E. Shelbrooke[4]
[1]The University of Toledo, OH, USA
[2]Vanderbilt University, TN, USA
[3]University of Cincinnati, OH, USA
[4]The University of Leeds, UK

Abstract--In-depth historical assessment of innovation over the past several hundred years shows that incremental innovation and cost reduction emphasized in the late 20th Century will prove inadequate and even counterproductive in the 21st Century for achieving sustained, global competitive advantage requiring radical innovation. The Accelerated Radical Innovation (ARI) Methodology, developed systematically over the past 5 years, has further addressed these requirements by utilizing systematic historical and real time case studies to articulate theory, tacit knowledge, techniques and tools for improving the radical innovation process.

Ongoing ARI research since the PICMET'07 Conference has further confirmed the validity of the ARI Methodology, and developed improved techniques for measuring and guiding innovation progress, based on focused assessment of 10 Innovation Attributes at each of the 10 ARI steps. A systematic evaluation of successful radical innovation approaches, and quantitative assessment of the dynamics of four major radical innovations over the past 100 years by retrospective application of the ARI theory have been applied to better understand how to overcome the four types of challenges and hurdles inherent in achieving commercialization of breakthrough innovations.

This paper summarizes research on the ARI Methodology at The University of Toledo since 2004, involving collaborators at Vanderbilt University, University of Detroit Mercy, Bowling Green State University, University of Cincinnati and University of Leeds, UK, from mid 2006 to the end of 2008. Approaches and techniques for real-time assessment and management of a potential breakthrough innovation are now validated to address any innovation stage from breakthrough concept to commercialization of a standard design.

1. HISTORICAL INNOVATION BACKGROUND FROM THE 18TH TO THE 21ST CENTURY

Prior to the 20th Century, economic development theory excluded technology as a determining factor. In the early 1900s Kondratieff [54] and Schumpeter [85] launched the study of the impact of science and technology on economic development, a concept initially overlooked because of emphasis on the linear innovation model described by Bush [15], Stokes [89] and Godin [44]. After a half century debate, Hirooka[46] and Perez [72] have now retrospectively modelled scientific technology revolutions in the form of Levitt's [58] growth curve framework, comprising 4 generic industrial product life cycle stages, representing development, growth, maturity and decline as shown in Figure 1. Acceptance of Levitt's pioneering concept had been delayed many years by Mahajan's empirical study [60] focusing on difficulties in fitting raw market data to a simple mathematical model of the product life cycle.

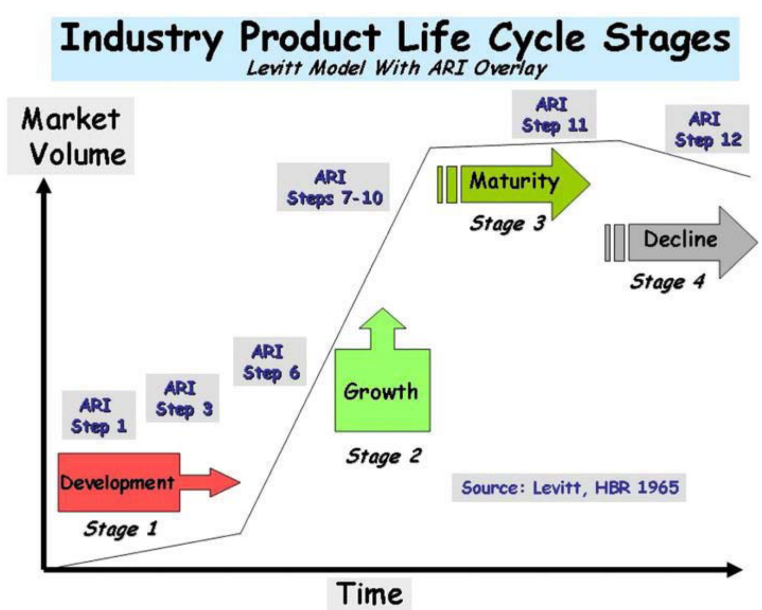


Figure 1. Generalized Life Cycle Stages of An Individual Product, Process or Service, Based on Levitt [58] and Shenhar [87-88]. See Appendix I for overlay of ARI Steps

Historical reluctance by academics, industrialists and governments to accept the concept of new scientific paradigms, first proposed by Kuhn [56], likewise delayed by approximately 50 years acceptance of the scientific technology revolution concept summarized by Perez [72] and Hirooka [46] and illustrated in Table 1 and Figure 2. The Perez model and Hirooka's growth curves, combining historical analysis with scenario forecasting [82-84, 95], made possible the correlation of lumped radical innovations of a common type with a particular scientific technology revolution. But the lack of real time techniques and tools to progress potential breakthrough innovations to commercialization motivated the authors to develop the Accelerated Radical Innovation (ARI) methodology to accomplish this task, as described in Section 3.

Table 1. Summary of Five Scientific Technology Revolutions, Represented as Lumped Radical Innovation Cycles (57 +/- 17 Years). See Perez [72], Hirooka [46] and Dismukes [26]

Scientific Technology Revolution	Period or Age	Core Region of Launch	Big Bang Event (feasibility)	Launch	Maturity (estimate)	Lifecycle Time (Years)
1st	1st Industrial Revolution	Britain	Arkwight Textile Mill	1771	1829	58
2nd	Steam and Railways	Britain (Europe & USA)	Rocket Steam Engine	1829	1873	44
3rd	Steel, Electricity, Heavy Engineering	USA & Germany (Britain)	Bessemer Steel Plant	1875	1918	43
4th	Oil, Automobile, Mass Production	USA (Germany/Europe)	1st Ford Model T	1908	1974	66
5th (Perez, 2002) (Hirooka, 2003)	Information, Telecommunications, Biotechnology, Nanotechnology	USA (Europe and Asia)	1st Intel Micro-processor	1971	2045	74

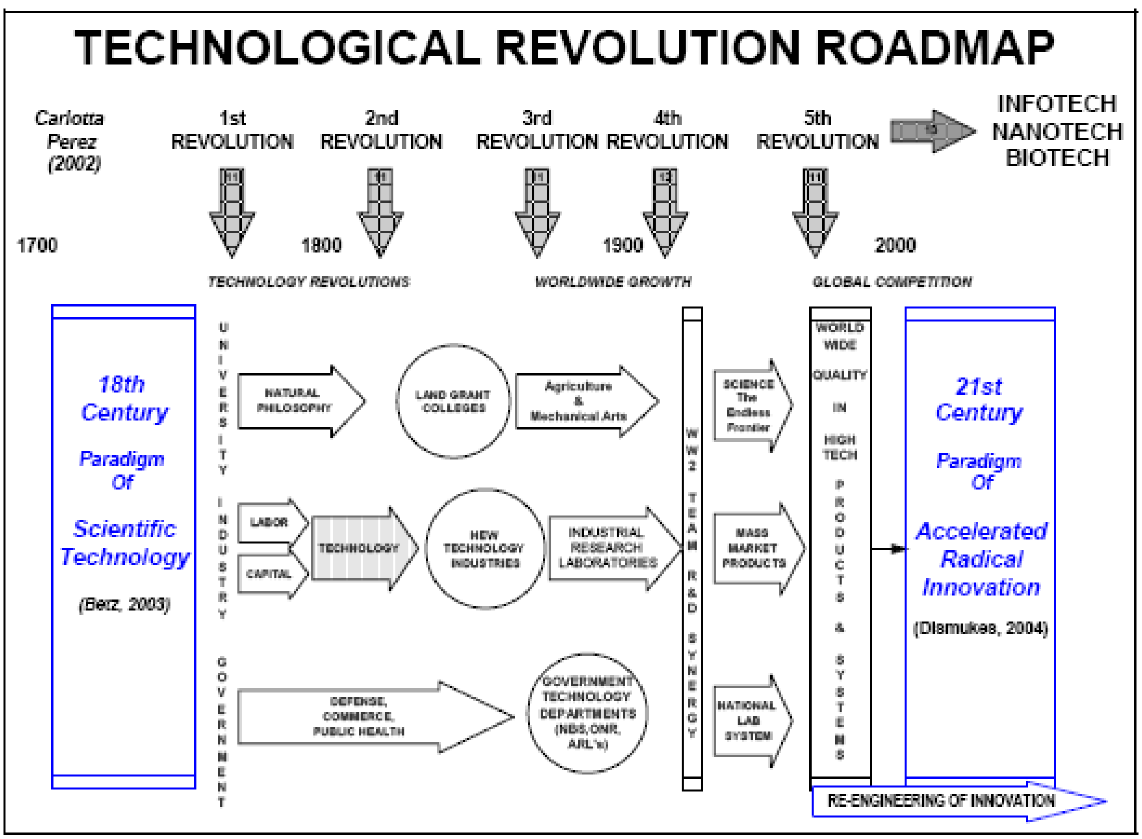


Figure 2. Innovation Roadmap from 18th Century Paradigm of Scientific Technology to 21st Century Paradigm of Accelerated Radical Innovation. See Betz [11] and Dismukes [26]

II. STATUS AND ASSESSMENT OF INCREMENTAL AND RADICAL INNOVATION

This section surveys the incremental and radical innovation field, followed in Section 3 by description of the Accelerated Radical Innovation (ARI) methodology developed since 2004.

A. Introduction and Overview

Exponential growth of innovation research since 1950 has produced studies addressing innovation described by various names, without achieving a universally accepted empirical or theoretical model for the radical innovation process [1]. Publications representing major milestones in the study of innovation include: Age [1], Anderson [2], Arnheiter [3], Atkinson [4], Auerswald [5], Betz [11], BCG [12], Burt [13], Bush [14], Chesbrough [15-17], Christenson [18-19], Cooper [20-23], Council on Competitiveness [48], Deming [24], Drucker [33-35], Eidt [36], Forrest [37], Foster [38-39], Fusfeld [40], Garrety [41], Garcia [42], Gerybadze [43], Godin [44], Grove [45], Hirooka [46], Hivner [47], Jenkins [50], Kelley [53], Kostoff [55], Kuhn [56], Leifer [57], Lynn [59], Moore [65], NRC [69-70], O'Connor [71], Petkovic [73], Rich [78], Roberts [79-80], Rogers [81], Stokes [89], Suh [90-91], Utterback [92-93], Voss [94], Walton [96], Wenger [97], and Womack [98-99]. ARI author contributions to radical innovation include Bers [6-10, 59], Dismukes [25-32], Miller [63], and Sekhar [86].

Despite the increase in published academic, industrial and governmental research discussed below, Age's 1995 thesis [1] that *"**there is no model for the innovation process**"*, is as true in 2009 as in 1995. In this paper the authors apply a concise innovation taxonomy [42] in Table 2, classifying innovation into two categories: ***incremental*** and ***radical***. Continuous is synonymous with incremental innovation, whereas discontinuous, breakthrough, or disruptive is synonymous with radical innovation. Chesbrough's "open innovation" classification [15-17] encompasses both incremental and radical innovation, including 2 categories of each in Table 2. As shown in Section 3 and Appendix I, this classification appropriately addresses the challenges and hurdles that must be overcome to accelerate radical innovation [26-27, 57].

B. Incremental Innovation Assessment

An innovation assessment by the authors identified only two major studies of hundreds of innovations [20, 67-68], focused on incremental innovations (Table 1) in established industries, with an average commercialization time of 3 years, and success correlated with classical business school success criteria, rather than with criteria for breakthrough or radical innovations.

The Stage-Gate® system methodology [20-23] pioneered by Robert Cooper is the most widely applied approach for commercializing low-tech or medium-tech incremental innovations summarized in Table 1. Illustrated in Figure 3 below is the Walton [96] Stage- Gate® system flow chart description, uniquely emphasizing iterative application of the Lynn [59] and Bers [6] probe and learn strategy for rapid "incremental innovation" development of a product, process or service meeting customer requirements. Strict adherence to total quality management (TQM) principles [24], lean manufacturing techniques [98-99] and Six Sigma techniques [3, 51] provide a basis for repeatable commercialization of low-tech incremental innovations. For more difficult medium technology incremental innovations, reliance on axiomatic design [90-91] techniques aided by TRIZ methods [100] improves success in profitable commercialization meeting customer requirements, typically in 4 years or less.

TABLE 2. FOUR INNOVATION CLASSIFICATIONS [26, 87-88] BASED ON TECHNOLOGY COMPLEXITY
a) Incremental (Low-Tech and Medium-Tech) and
b) Radical: (High-Tech and Super High-Tech)

Differentiating Innovation Characteristics	**Incremental Innovation**		**Radical Innovation**	
	Low-Tech	Medium-Tech	High-Tech	Super-High-Tech
Technology	No New Technology	Some New Technology	Integration of New, Existing Technology	Development and Integration of New Technology and System
Scope of Product or Service	Existing Material, Component, Subsystem, Array	Some Newness of Scope	Major Newness of Scope	Very Broad Newness of Scope
Time (months, years, decades)	Months to One Year	Months to Several Years	Several to Many Years	Many Years to Decades
Organization Size	Small, Medium or Large	Small, Medium, or Large	Venture, Small, Medium or Large	Venture, Small, Medium or Large
Industry	Product, Process and Service Providers	Product, Process and Service Providers	Product, Process and Service Providers	Product, Process and Service Providers
Supply Chain or Value Chain	Regional, National or Global	Regional, National or Global	Regional, National or Global	Regional, National or Global
Market	Known Market and Customer	Known Market and Customer	Anticipated Customer	Anticipated New Product or Service Need
Company Structure and Culture	Age, Core Values, Vision	Age, Core Values, Vision	Age, Core Values, Vision	Age, Core Values, Vision

US companies over the past 30 years have predominantly focused on incremental innovation and cost reduction, to achieve commercialization within approximately 1-4 years. However, the 2004 Council on Competitiveness study [48], substantiated by review and feedback over the past 4 years, has proposed that a focus only on incremental innovation will be less effective and potentially counterproductive in the 21st Century environment, characterized by substantial worldwide funding of breakthrough technologies. The next subsection assesses the current status of radical or breakthrough innovation.

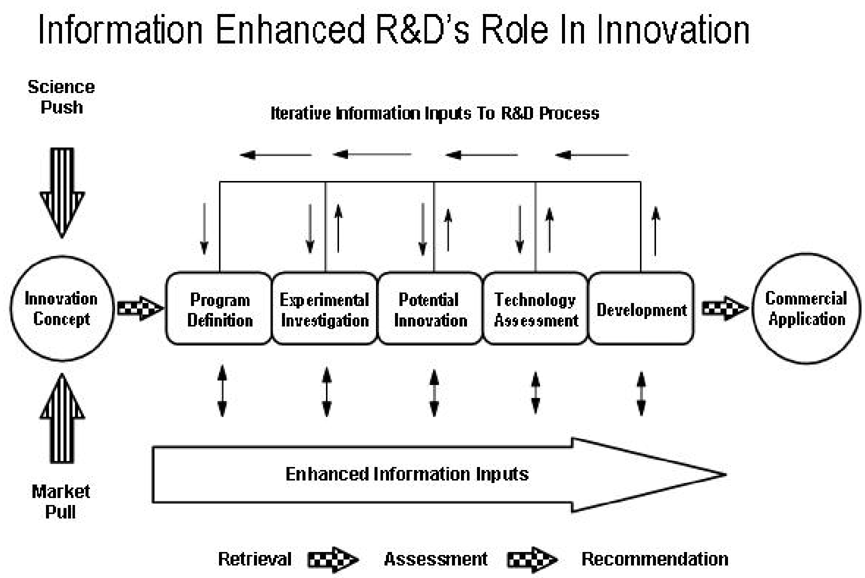
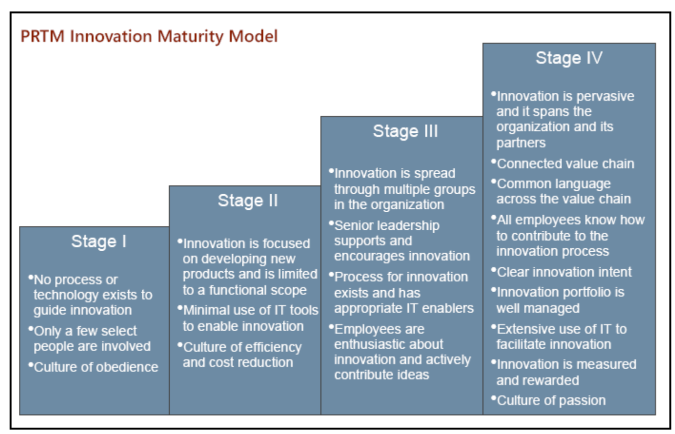


Figure 3. A Stage-Gate® System Flow Chart Suitable for Commercialization of an Incremental Innovation (see Table 1)

C. Radical or Breakthrough Innovation Assessment

Competitive intelligence literature searches and discussions with radical innovation practitioners revealed widespread interest in improving the success of commercializing breakthrough technologies that could launch new radical innovations in industrial technology life cycles as illustrated in Table 1 and Figure 1. Studies by the Information Technology and Innovation Foundation [4], the National Research Council [70], the Boston Consulting Group, Inc.[12] and PRTM, Inc.[64] proposed generic strategies, but did not disclose specific techniques and tools for managing radical innovation dynamics. One example is PRTM's four-stage approach, Figure 4, that provides an industrial company with organizational structure and culture guidelines needed for profitable commercialization of emerging, breakthrough technologies.

Understandably, major corporations and venture companies are reluctant to divulge proprietary techniques and tools that might provide competitors a competitive advantage in breakthrough commercialization. In addition, discovery and documentation of techniques and tools based on real time study of radical innovations is inherently difficult, given the fact that conversion of an emerging breakthrough technology into a profitable, industry leading standard, dominant design [2, 46, 72] typically requires 15-30 years or longer for a high-tech or super-high-tech radical innovation illustrated in Table 1. Therefore inductive recognition of techniques and tools may not happen unless there is dedicated organizational leadership goal.



Source: PRTM

Figure 4. 4-Stage Capability Development Roadmap by PRTM [64] to Position a Company to Compete for Commercializing Specific Radical Innovation Opportunities

Although we did not find disclosure of predictive techniques and tools for managing the development and commercialization of radical innovations, we did find published historical conclusions from four major industrial corporations (General Electric, AT&T, DuPont and Exxon-Mobil) that shed light on prerequisites for effective management of breakthrough innovations.

Betz [11] has documented General Electric's approach, in response to anticipated technology threats, to develop a next-generation radical innovation light bulb with a long lasting tungsten filament displacing the carbon filament pioneered by Edison in the first light bulbs. Guided by effective technological and cost assessment of new and potentially superior filament materials, General Electric at the beginning of the 20th Century researched, patented and commercialized the tungsten filament light bulb.

AT&T vice president Jack Morton [66] also described a winning innovation strategy adopted at Bell Laboratories in the late 1930's to develop a more energy efficient switching technology to replace vacuum tubes that, based on market forecasts, would require more energy than could at that time be supplied by the existing US electrical distribution grid. Although laypeople typically attribute this breakthrough to pure, Nobel prize winning scientific research on solid state materials to develop transistors, the motivation for that research was research management's accurate forecast that the growing telephone market could not be supported by the energy inefficient switching technology based on vacuum tubes.

DuPont vice president Joseph Miller[62] also published a historical assessment of breakthrough technology commercialization at DuPont over more than half a century. Though he did not disclose proprietary details, he noted that breakthrough innovations commercialized at DuPont occurred in cycles of 15-20 years, suggesting a linkage of DuPont's expertise in emerging technology breakthroughs to profitable opportunities in chemical materials markets.

Clarence Eidt [36], president of Exxon's downstream research and engineering company in 1997, reported on a company-wide strategic assessment and re-direction of their industrial basic research. The new strategy clearly focused centralized and decentralized research and development on major business and market opportunities identified by consensus at a top management level in the corporation. This strategy, analogous to that of DuPont, clearly focused innovative research and development on the best commercial market opportunities, and likewise did not reveal specific predictive techniques and tools for accomplishing this.

Finally, review of Peter Drucker's [34] monograph on innovation and entrepreneurship, shows that almost 25 years ago he summarized on page 35 and in subsequent chapters key factors that must be monitored to identify desirable major innovation opportunities. These seven factors, listed below, provide further qualitative guidelines for development and commercialization of radical innovation opportunities:

1. unexpected success, unexpected failure, or an unexpected outside event
2. incongruity between actual reality and reality as it is assumed to be or ought to be
3. innovation based on process need
4. changes in industry or market structure that catch everyone unawares
5. demographics (population changes)
6. changes in perception, mood and meaning
7. new knowledge, both scientific and nonscientific

The pioneering studies by Perez [72] and Hirooka [46] of 5 industrial revolutions, summarized in Table 1, focused on lumped radical innovations of a common technological type with an average duration of 57 ± 17 years, but did not focus on individual innovations. To better understand the evolution of individual major innovations, in Table 3 we have retrospectively applied the 10 ARI Methodology Steps of Section 3.3 and Figure 5 to analyze several high profile innovations of the past 100 years. The four prominent 20th Century radical innovations selected and illustrated in Table 3 below are: Atomic Bomb, GMO in Food Products, Powered Flight, and Wind Electricity.

Table 3 provides insight into the requirements for the Accelerated Radical Innovation Methodology, because with the exception of the Atomic Bomb, innovation time from concept (Step 1) to commercialization (Step 10), was much longer than an acceptable business management goal of ≤15 years for even the most visionary industrial corporation. This result sheds understanding on the reluctance of most corporations in the late 20th Century to focus resources on the search for truly breakthrough technological innovations [48].

Although the average time for commercialization of the four innovations in Table 3 is approximately 61 years, there a wide variability suggesting that achieving desired commercialization times of ≤15 years will be very difficult, unless the inevitable challenges and hurdles of breakthrough innovations are addressed. This will require enhanced computing and more rapid telecommunications technologies in conjunction with strong top management leadership in an open innovation environment [15-17], together with application of the ARI Methodology, to reduce commercialization time. The "Atomic Bomb", representing the most accelerated innovation known, substantiates the fact that ***response to crisis*** identified by Grove [45] is a powerful stimulus to speeding up innovation ***because it motivates stakeholder alignment and dedicated resources with a common purpose.***

TABLE 3. HISTORICAL ASSESSMENT OF FOUR KEY 20TH CENTURY RADICAL INNOVATION LIFE CYCLES

ARI Step	ARI Methodology Step Description	Time To Reach ARI Step (Years)			
		Atomic Bomb	GMO in Food Products	Powered Flight	Wind Electricity
1	Recognize Threat or Opportunity	1	10	1	1
2	Define breakthrough and life cycle position	9	17	4	8
3	Challenge 3a: Market / Societal	6	27	14	10-115
	Challenge 3b: Scientific / Technological	9	2-3	4-7	10-115
	Challenge 3c: Business / Organizational	9	25	12	88-115
	Challenge 3d: Cluster / Network	9	27	24	88-115
4	Identify Key ARI Hurdles	8	17-27	24	10-115
5	Assess Hurdles	8	25-35	24	83-115
6	Establish ARI System Vision	8	25	24	88
7	Form Value Network	9	35	12-49	88-105
8	Accelerate Innovation Prototyping	9	25	7-34	100-115
9	Test Prototype Design	12	25	7-54	110-115
10	Establish Radical Innovation Standard Designs Onshore / Offshore	12	35	54	140

III. THE ACCELERATED RADICAL INNOVATION (ARI) METHODOLOGY

A. Potential for Wide Commercial Application

A 2004 Council on Competitiveness study [48] concluded that with a few exceptions, in the late 20th Century industrial managers in the United States focused primarily on cost reduction and incremental innovation. One key exception was breakthrough military and aerospace systems innovation in support of the former "cold war" with the Soviet Union, conducted by the Lockheed "skunk works" [50,78]. Another key exception was the DARPA innovation response [61] addressing potential threats to US national security from biological or information technology. These exceptions, though on a smaller scale than those of World War II in the 1940's, are reminiscent of the successful, US government coordinated industry-university-government collaboration leading to the development of the Atomic Bomb, and commercialization of nuclear electric power plants [14].

These lessons are potentially transferrable under conditions of large scale societal need, such as the current US and worldwide economic crisis, to identify opportunities for accelerated development and commercialization of products, processes, services and large scale systems or mega-systems ("arrays") [87-88]. This could provide impetus for further concerted development and systematic application of the Accelerated Radical Innovation (ARI) methodology [6-10, 25-32, 86] discussed in the next sections and in Appendix I and Appendix II.

B. ARI Methodology Development From 2004 to 2009

In May 2004 the ECI International Conference on Accelerating the Radical Innovation Process [25] launched ARI methodology development, and provided the basis for the initial publication in this field [28]. Over the next five years further development of the ARI methodology was reported in a sequence of conferences, workshops and publications:

- December 2004 Indo-US Forum on Radical Innovation [7] in Trivandrum, Kerala, India,
- March 2005 International Workshop on Accelerated Radical Innovation [27, 29], held in Toledo, Ohio at The University of Toledo,
- August 2005 PICMET'05 Conference[6] Presentation,
- August 2007 PICMET'07 Conference [8, 30] Presentation, Tutorial, and Proceedings, that included a University of Leeds, UK, report [49] on "Developing Radical Innovation Practices in UK Healthcare and Medical Technologies",
- October 2008 presentation at the Medical Innovation Forum, Harrogate, UK [32].
- 2008-2009 publications in Technological Forecasting and Social Change [9, 31, 86].

The latest results described in this paper have been partially supported by a University of Leeds, White Rose Health Innovation Partnership (WRHIP) subcontract funded by a major UK government grant. The research was coordinated by an ARI team at University of Toledo, interacting with collaborators at Vanderbilt University, Bowling Green State University, University of Detroit Mercy, University of Cincinnati, as well as the University of Leeds.

C. Description of the Current ARI Methodology

This section summarizes the basic methodology for Accelerated Radical Innovation (ARI), shown schematically below in Figure 5, with reference to the 4 Grand Challenges in Figure 6, to 10 innovation attributes (Figure 7), and to use of innovation attributes (Figure 8) to measure progress and guide completion of the innovation. As shown in Figure 5, the Steps 1-10 of the ARI Methodology provide a template for progressing an identified "potential innovation", aided by competitive intelligence at each of the ten ARI Steps [55, 59, 63, 69-70, 74-77].

The ARI methodology begins with the identification or recognition of an opportunity or threat [45, 57] followed by assessment of challenges and hurdles in each of the four areas of Figure 6, namely:

- Market and Societal Challenges,
- Scientific and Technological Challenges,
- Business and Organizational Challenges, and
- Cluster and Network Challenges.

Successful competitive assessment [52, 55, 63] of these challenges and how to overcome the identified hurdles leads to an innovation vision and business plan at the conclusion of the Inception Period, Step 6. This includes a business model needed to obtain and distribute value to all stakeholders, and a commercialization strategy for progressing the potential breakthrough innovation through the value chain identified at Step 7. Guided probe and learn assessment [6,59] and testing of radical innovation prototypes at Step 8 lead to validation of a prototype design at Step 9, culminating finally at Step 10 in successful commercialization of a radical innovation standard design.

Appendix I provides a detailed list summarizing the requirements of the four Grand Challenge Areas of Step 3 in Figure 5 and Figure 6.

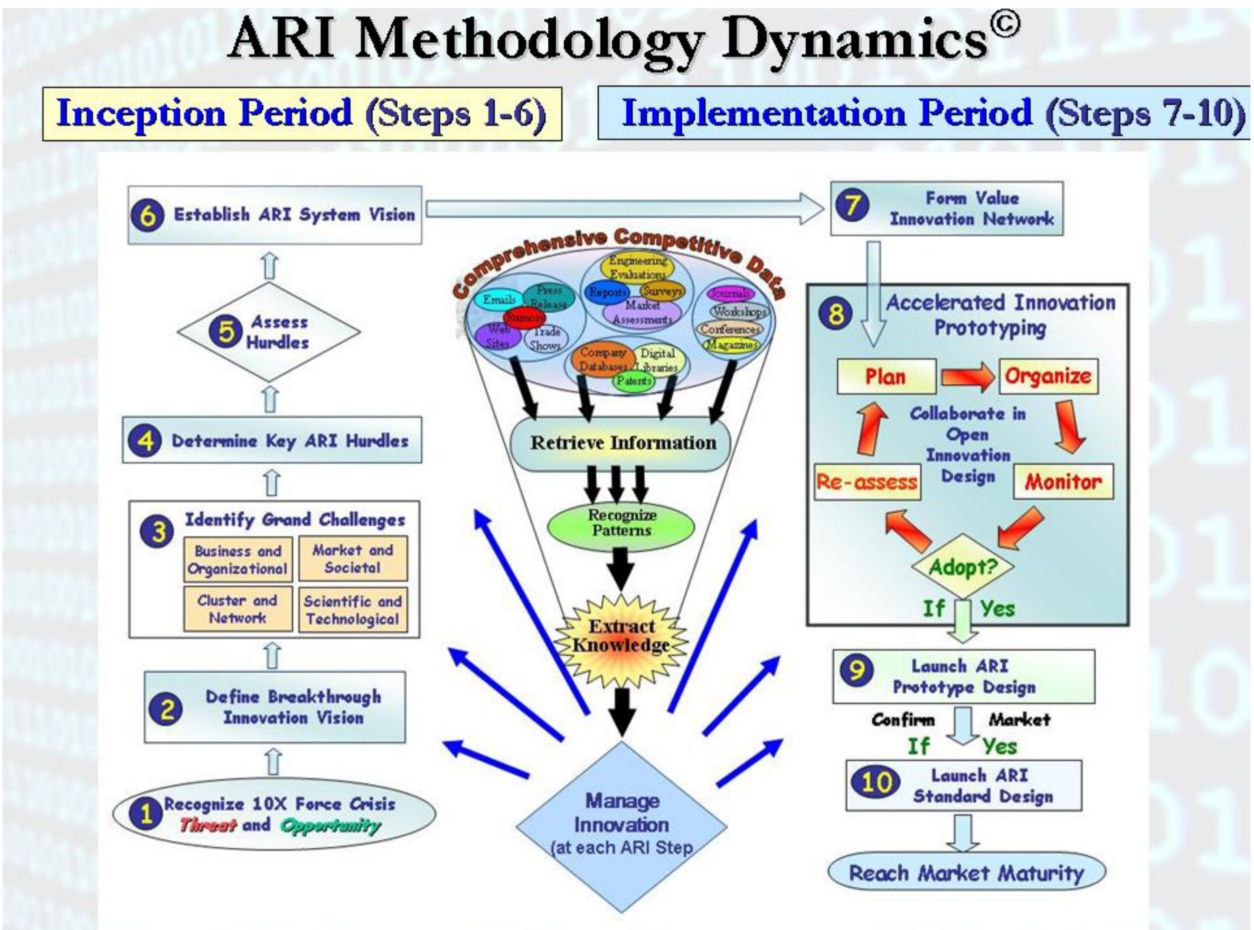


Figure 5. The 10-step ARI Methodology Framework comprises the Inception Period (Steps 1-6) concluding with a system vision or business plan, and the Implementation Period (Steps 7-10), beginning at Step 7 with a commercialization plan and concluding at Step 10 with commercialization of a standard design. See references [6-10, 18-19, 30-32]

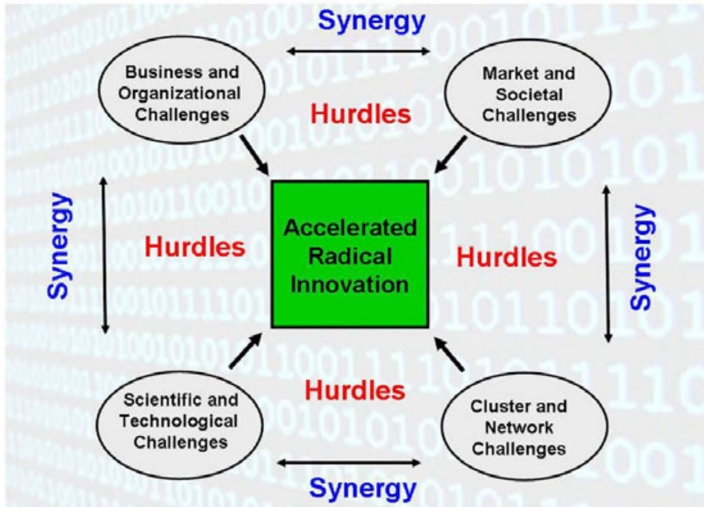


Figure 6. The four grand challenges and hurdles to achieving accelerated radical innovation: I) Scientific and Technological Challenges, II) Business and Organizational Challenges, III) Market and Societal Challenges, and IV) Cluster and Network Challenges [27].

D. Advanced Technique Under Investigation for Improving the ARI Methodology

Clearly the ideal ARI model shown in Figure 5 is not strictly linear, but incorporates the possibility of cyclical or spiral feedback loops between ARI Steps that can be managed by an innovation team to enhance innovation acceleration from Step 1 through Step 10 of the ARI Methodology. A promising technique, developed and initially applied during the last year to a proprietary innovation being explored by the University of Leeds WRHIP Program, is tailored to real time analysis of 10 Innovation Attributes (i.e. characteristics) (Figure 7) at each of 10 ARI Steps. This technique bases its success on asking and answering a series of ***Progress Status Questions***, unique to each ***Innovation Attribute***, followed by matching the answers to "Innovation States" representing the "degree of accomplishment" at each ARI Step, relative to that required for commercialization of a standard design at Step 10. This enables plotting innovation progress, shown illustratively in Figure 8, enabling the innovation team to:

- Determine its degree of accomplishment at each of the 10 ARI Steps,
- Establish what further knowledge is needed and actions required, and
- Identify competitive intelligence and guided probe and learn activities appropriate for progressing the innovation to the end goal of commercialization of a standard design.

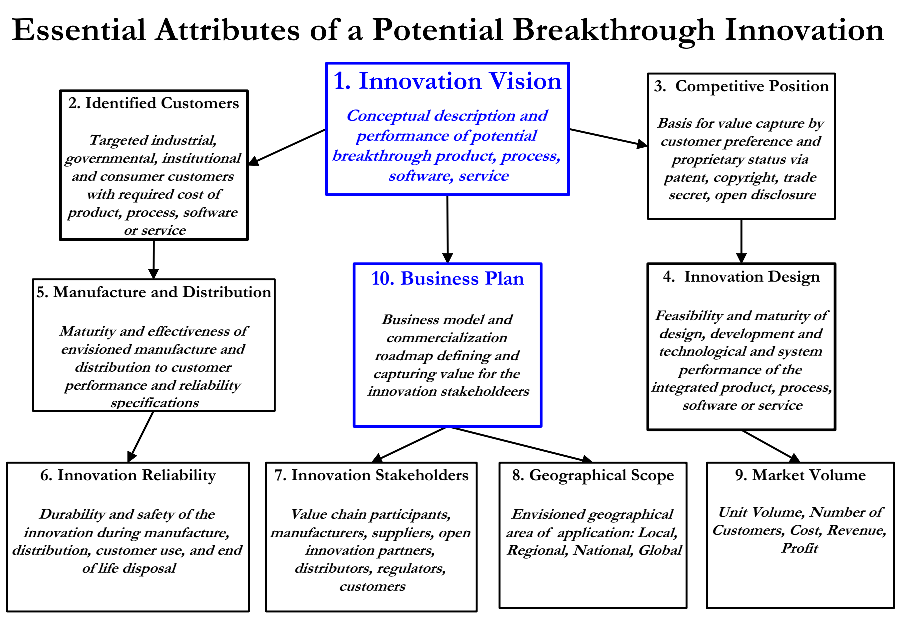


Figure 7. Essential Attributes of a Potential Breakthrough or Radical Innovation

By answering ***Progress Status Questions***, and matching the current progress of the innovation to ***Progress Status States*** mapping the "degree of accomplishment" at each ARI Step, as shown illustratively in Figure 8, the innovation team can

- Correctly determine its degree of accomplishment at that Step,
- Accurately determine what further knowledge is needed and actions required,
- Determine what "competitive intelligence tools" to apply to obtain the necessary information to catalyze accelerated innovation development,
- Conduct programmatic actions to overcome hurdles revealed by updated of Grand Challenges assessments.

A sample analysis of the application of innovation attributes for this purpose is illustrated in Appendix II, for Innovation Attribute 4: Innovation Design.

ARI STEP —— Progress Status Score (as percentage of required progess at Step 10)

Innovation Attribute	1. Innovation Vision	2. Identified Customers	3. Competitive Position	4. Innovation Design	5. Manufacture and Distribution	6. Innovation Reliability	7. Innovation Stakeholders	8. Geographical Scope	9. Market Volume	10. Business Plan
1	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
2	40%	30%	40%	30%	30%	30%	30%	30%	30%	30%
3	50%	40%	50%	40%	40%	40%	40%	40%	40%	40%
4	60%	50%	60%	60%	50%	50%	50%	50%	60%	60%
5	70%	60%	70%	70%	60%	60%	50%	60%	60%	60%
6	80%	70%	80%	80%	70%	60%	60%	60%	60%	80%
7	80%	80%	80%	80%	80%	70%	70%	70%	70%	80%
8	80%	80%	80%	90%	80%	80%	80%	80%	80%	90%
9	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
10	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 8. Progress Status Ratings of 10 Innovation Attributes for a Potential Breakthrough Innovation as a Function of ARI Step from Step 1 to Step 10. Percentage scores indicate the percentage of required progress at Step 10 that must be achieved for accelerated commercialization.

IV. CONCLUSIONS

The characteristics and behavior of incremental and radical innovations over the past century have been assessed and compared, focusing on these two types as descriptive of the large number of different taxonomies used. Increasing standardization of understanding and application of incremental innovation is noted: particularly for Stage-Gate®, Lean Manufacturing, Six Sigma techniques.

For radical innovation, particularly for standard design commercialization times exceeding 10-20 years, normative and descriptive historical methodologies are far advanced. However, quantitative techniques have been lacking both because of the long times involved, reluctance to divulge data, and due to the lack of a holistic model for describing, managing and measuring the process.

Confirmation of the value of the 10-step ARI Methodology has been established for accelerating development and commercialization of radical or breakthrough innovations. The paradigm focuses correctly on systematic assessment of challenges and hurdles and assembling appropriate people teams to work on the innovation over an extended period. In the five years since the proposal by our ARI team that such a methodology should be developed to speed up breakthrough innovations, considerable progress has been made in developing a model that describes the radical innovation process, and in identifying required team efforts and techniques to manage breakthrough or radical innovation development and commercialization.

A 30-month UK grant to the University of Toledo via the White Rose Health Innovation Partnership (WRHIP) at The University of Leeds has provided stimulus for this effort, as well as valuable experience.

REFERENCES

[1] Age, J.O., Development of a Model for Technological Innovation Process, Technology Management, 1995. **2**: p. 291-292.

[2] Anderson, P. and Tushman, M. L., Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change, Administrative Science Quarterly, Volume 35, pp. 604-633 (1990).

[3] Arnheiter, E. D. and Maleyeff, J., "Integration of Lean Management and Six Sigma", The TQM Magazine, Volume 17, No. 1, pp. 5-18 (2005).

[4] Atkinson, R.D. and Andes, S. M., The Atlantic Century: Benchmarking EU & U.S. Innovation and Competitiveness, February 25, 2009, 40 pages, The Information Technology and Innovation Foundation, 1250 I Street, NW, Suite 200, Washington, D.C. 2005, available at: http://www.itif.org/files/2009-atlantic-century.pdf

[5] Auerswald, P. E. and Branscomb, L. M., "Valleys of Death and Darwinian Seas: Financing the Invention to Innovation Transition in the United States," *Journal of Technology Transfer,* vol. 28, pp. 227-239, 2003.

[6] J. Bers and A. Kamat, "The Critical Role of Simulation and Modeling in Accelerating the Radical Innovation Process," in *First International Conference on Accelerating the Radical Innovation Process* Charleston, SC, 2004; and.Bers, J. A., Contributions of Social Constructionism to a Theory of Accelerated Radical Innovation, Proceedings of the 2005 Portland International Conference on the Management of Engineering and Technology, 2005, Portland, OR USA.

[7] Bers, J.A. and Dismukes, J. P., Presentation on Accelerated Radical Innovation, Indo-US Forum on Innovation and Radical Innovation, Trivandrum, India, December 27-31, 2004.

[8] Bers, J. A. and Dismukes, J. P., "Principles and Practice of Accelerated Radical Innovation", PICMET 2007 Proceedings ISBN CD ROM: 1-890843-15-6, pp. 739-752, 2007.

[9] Bers, J. A., Dismukes, J. P., Miller, L. K., and Dubrovensky, A., Accelerated Radical Innovation: Theory and Application, Technological Forecasting and Social Change, 2009. **76**(1): p. 165-177.

[10] Bers, J. A., and Dismukes, J. P., "Accelerated Radical Innovation: The Execution Side", Final Submitted to PICMET'09 Conference, April 2009.

[11] Betz, F., "Managing Technological Innovation: Competitive Advantage From Change", 2nd Edition, John Wiley & Sons, New York, NY, ISBN# 0-471-22563-0, (2003)

[12] Boston Consulting Group, Exchange Place, 31st Floor, Boston, MA 02109, The Innovation Imperative in Manufacturing: How the United States Can Restore Its Edge, Andrew, J., DeRocco, E. S., Taylor, A., March 9, 2009, available at www.bcg.com . *To compete against global challengers from low-cost countries, companies in the U.S. must differentiate themselves through innovation. And government--at both the national and the local level--must support these efforts through effective policies. The payoff is enormous: countries with thriving industries have a higher standard of living and a better quality of life than other nations. This report assesses the state of innovation in the U.S. compared to other countries and explores how to encourage and sustain innovation.*

[13] Burt, Ronald S., "The Network Structure of Social Capital", in Research in Organizational Behavior, R. I. Sutton, B. M. Staw, Editors, JAI Press, Greenwich, CT, pp. 345-423 (2000).

[14] Bush, Vannevar, 1946, Science – The Endless Frontier: A Report to the President on a Program for Postwar Scientific Research, Reviewed in SCIENCE and TECHNOLOGY POLICY YEARBOOK 1994, AAAS, Washington DC, 1994.

[15] Chesbrough, H.W., Open Innovation: The New Imperative for Creating and Profiting From Technology, 2003, Boston: Harvard Business School Press.

[16] Chesbrough, H. and Rosenbloom, R.S., "The Role of the Business Model in Capturing Value from Innovation: Evidence from Xerox Corporation's Technology Spin-Off Companies", Industrial and Corporate Change, Vol. 11, No. 3, pp. 529-555 (2002).

[17] Chesbrough., H. W., Open Business Models: How to Thrive in the New Innovation Landscape, Harvard Business School Press, 2006.

[18] Christensen, C.M. and Raynor, M. E., The innovator's solution: creating and sustaining successful growth, 2003, Boston, Mass.: Harvard Business School Press, 304 pages.

[19] Christensen, C. M., "The Ongoing Process of Building a Theory of Disruption", Journal of Product Innovation Management, Vol. 23, Issue 1, 39-55 (2006).

[20] Cooper, R. G., Project Newprod: What Makes a New Product a Winner? – An Empirical Study of Successful versus Unsuccessful Industrial Product Innovation, Quebec Industrial Innovation Center, . Montreal, Canada, 1980.

[21] Cooper, R.G., Edgett, S.J. and Kleinschmidt, E.J., "Optimizing the Stage-Gate Process: What Best-Practice Companies Do-I, Research Technology Management, Volume 45, September-October, 2002, pp. 21-27. .

[22] Cooper, Robert G., Edgett, Scott J. and Kleinschmidt, Elko J., "Optimizing the Stage-Gate Process: What Best-Practice Companies Do-II, Research Technology Management, Volume 45, November-December, 2002, pp. 43-49.

[23] Cooper, R. G., "How Companies Are Reinventing Their Idea –to-Launch Methodologies, Research-Technology Management Volume 52, No. 2, March-April, 2009, pp. 47-57.

[24] Deming, W. E., "Out of Crisis", MIT Center for Advanced Engineering Study, ISBN#0-911379-01-0, 1988.

[25] Dismukes, J.P., et al., Organizers, ECI Conference on "Accelerating the Radical Innovation Process", Charleston, SC, USA, May 16-21, 2004; Complete Conference Agenda available at http://www.engconfintl.org/pastconf/4akfin.pdf

[26] Dismukes, J. P., "Information Accelerated Radical Innovation: From Principles to an Operational Methodology", The Industrial Geographer, Vol 3, Issue 1, pp. 19-42 (2005); accessed at http://igeographer.lib.indstate.edu/dismukes.pdf

[27] Dismukes, J. P., International Workshop on Accelerated Radical Innovation, (IWARI2005), March 10-12, 2005, Toledo, Ohio, CDROM Report, September 2005, accessed via. http://www-iwari2005.eng.utoledo.edu/,

[28] Dismukes, J.P., *Accelerate Radical Innovation Now!* Research-Technology Management, 2004. Vol. 47, Sept.-Oct., p. 2-4.

[29] Dismukes, J. P., Bers, J. A., Miller, L. K., and McCreary, W. N., "*Technologies of Thinking* Seen Key to Accelerated Radical Innovation", Research-Technology Management, Vol 48, July-Aug, pp. 2-4 (2005).

[30] Dismukes, J. P., Tutorial Session 07T0008, "Accelerated Radical Innovation in the Industrial Technology Life Cycle", PICMET'07 Conference: "Management of Converging Technologies", August 5-9, 2007, Portland, OR, USA.

[31] Dismukes, J.P., Bers, J. A., and Miller, L. K., *The industrial life cycle of wind energy electrical power generation - ARI methodology modeling of life cycle dynamics.* Technological Forecasting and Social Change, 2009. **76**(1): p. 178-191.

[32] Dismukes, J. P., Miller, L. K., Bers, J.A., and Shelbrooke, A. E., "Accelerating Radical Innovation in Health: Theory and Practice",

Medical Innovation Forum Workshop, Harrogate, UK, October 21, 2008.
[33] Drucker, P. E., "Management Challenges for the 21st Century", Harper Collins Publishers, New York, NY, 1999.
[34] Drucker, P. E., "Innovation and Entrepreneurship", Harper and Row Publishers, ISBN# 0-06-015428-4, New York, NY 1985.
[35] Drucker, P. E., The Discipline of Innovation, Harvard Business Review, pp. 67-71, May-June, 1985.
[36] Eidt, C. M. Jr., and Cohen, R. W., "Reinventing Industrial Basic Research", Research- Technology Management, Vol. 40, January-February 1997, pp. 29-36. OVERVIEW: Currently, much is being said and written about the decline of longer-range R&D in the U.S., and industrial basic research in particular (1). Exxon has maintained its commitment to basic research but has undertaken a major redesign of its management system aimed at significantly increasing the commercial impact of the effort. The new system utilizes a hybrid arrangement to capture the best characteristics of both centralized and decentralized alternatives. Other key features include: 1) business input from all management levels -- senior corporate officials to plant operators; 2) a business-driven approach that articulates targeted science advances in clear technical terms; and 3) a seamless link to ongoing applied development research activities via integrated planning, execution and stewardship systems. Both anecdotal and quantitative feedback indicate that the desired increase in commercial impact is' being achieved.
[37] Forrest, J. E., "Models of the Process of Technological Innovation", Technology Analysis and Strategic Management, Volume 4, No. 4, 439-452 (1991).
[38] Foster, R. N., "The Attackers Advantage", Simon and Schuster Publishers, New York, NY, 1986.
[39] Foster, R. N. and Kaplan, S., "Creative Destruction", ISBN # 0-385-50133-1, Doubleday Publishers, New York, NY, 2001.
[40] Fusfeld, H. I., 1994, Industry's Future: Changing Patterns of Industrial Research, American Chemical Society, Washington, DC.
[41] Garrety, K., Robertson, P. L., and Badham, R., "Integrating Communities of Practice in Technology Development Projects", International Journal of Project Management, Volume 22, pp. 351-358 (2004).
[42] Garcia, R. and Calantone, R., "A critical look at technological innovation typology and innovativeness terminology: a literatue review", Journal of Product Innovation Management Volume 19, pp. 110-132 (2002).
[43] Gerybadze, A. and Reger, G., Globalization of R&D: Recent Changes in the Management of Innovation in Transnational Corporation, Research Policy, Vol. 28, pp251-274, 1999.
[44] Godin, Benoit, "The Linear Model of Innovation: The Historical Construction of an Analytical Framework", Science, Technology & Human Values, Volume 31, Number 6, pp. 639-667, November (2006).
[45] Grove, A.S., "Only The Paranoid Survive: How To Exploit the Crisis Points that Challenge Every Company", Doubleday, New York, NY (1996)
[46] Hirooka, M., "Nonlinear dynamism of innovation and business cycles", J. Evol. Econ. Volume 13, pp 549-576 (2003).
[47] Hivner, W., Hopkins, S. A., and Hopkins, W. E., "Facilitating, accelerating and sustaining the innovation diffusion process: an epidemic modeling approach", European Journal of Innovation Management, Volume 6, Number 2, pp. 80-89, 2003.
[48] *"Innovate America National Innovation Initiative Report"*, Council on Competitiveness, Washington, DC, 1st Edition, 2004; available at http://www.compete.org/ .
[49] Holt, G., White, J., and Williams, R. A., "Developing Radical Innovation Practices in UK Healthcare and Medical Technologies", PICMET 2007 Proceedings, PICMET ISBN CD ROM: 1-890843-15-6, pp. 766-772, 2007.
[50] Jenkins, D. R., "Lockheed Secret Projects: Inside The Skunk Works", ISBN 0-7603-0914-0, MBI Publishing Compan, St. Paul, MN, 2001.
[51] Johnson, A. and Swisher, B., Managers at Work: How Six Sigma Improves R&D, Research-Technology Management, Vol. 46, No. 2, March-April, pp. 12-15 (2003)
[52] Juhari, A. S. and D. Stephens, D., "Tracing the Origins of Competitive Intelligence Throughout History." *Journal of Competitive Intelligence and Management*, Vol.3, No. 4, 2006, pp. 61 – 82.
[53] Kelly, P. and Kranzberg, P., Editors, Technological Innovation: A Critical Review of Current Knowledge, San Francisco Press, San Francisco, CA, 1978
[54] Kondratiev, N. D., Die langen Wellen der Konjuktur, Archiv fur Sozialwissenschaft und Sozialpolitik, Vol. 56, 573-606 (1926).
[55] Kostoff, R. N., "Systematic Acceleration of Radical Discovery and Innovation in Science and Technology", Technological Forecasting and Social Change, Volume 73, pp 923-936, 2006.
[56] Kuhn, T. S., "The Structure of Scientific Revolutions", 3rd Edition, The University of Chicago Press, ISBN # 0-226-45808-3, The University of Chicago Press, Chicago, Illinois, USA, 1996.
[57] Leifer, R., McDermot, C. M., O'Connor, G. C., Peters, L. S., Rice, M., and Veryzer, R. W, "Radical Innovation: How Mature Companies Can Outsmart Upstarts", Harvard Business School Press, Boston, MA (2000).
[58] Levitt, T., *EXPLOIT the Product Life Cycle.* Harvard Business Review, Volume 43, No. 6, pp. 81-94 (1965).
[59] Lynn, G.S., J.G. Morone, and A.S. Paulson, *Marketing and discontinuous innovation: The probe and learn process.* California Management Review, 1996. **38**(3): p. 8.; and Bers, J. A. and Kamat, A., "The Critical Role of Simulation and Modeling in Accelerating the Radical Innovation Process", presentation at 1st ECI International Conference on Accelerating the Radical Innovation Process, Charleston, S.C., USA, March 16-21, 2004.
[60] Mahajan, V., Muller, E., and Bass, F. M., New Product Diffusion Models in Marketing: A Review and Directions for Research, Journal of Marketing, Vol. 54, pp. 1-26 (1990).
[61] Marshall, Elliot, "Too Radical for NIH? Try DARPA", Science, Vol. 275, No. 5301, p. 744, February 7, 1997.
[62] Miller, J. A., Discovery Research Re-Emerges in DuPont, Research-Technology Management, Vol. 40, January-February, pp. 26-36, 1997. OVERVIEW: Alternative corporate strategies of growth and of consolidation result in a changing focus for research and development. Over the past 70 years, the DuPont Company has passed through four recurring cycles, each lasting 15-20 years. Within each cycle, the emphasis shifts from a period of discover, research to a later period of consolidation. It is the interplay between these phases that has shaped today's DuPont Company. The cause for this regularity in the cycles remains a puzzle. If history repeats itself, a new cycle is beginning and DuPont is on the verge of another burst of discovery research. Observers have noted that basic technological innovations seem to occur in "bursts" or clusters in cycles of approximately 50 years, spurred by investor demand for new growth opportunities (1, 2). Each "burst" is followed by a "long economic and investment wave," a period during which further discoveries and inventions are made extending and applying the new technology (3).
[63] Miller, L. K., Miller, R. H., and Dismukes, J. P., "The Critical Role of Information and Information Tecnology in Future Accelerated Radical Innovation", Information, Knowledge, Systems Management Vol. 5, No. 2, pp. 63-69 (2005-2006).
[64] Mohammad, M. and Romeri, M., The Road Map for Innovation Success, 16 pages, 2007, PRTM, 1050 Winter Street, Waltham, MA 02451, available at: http://www.innovationtools.com/PDF/Roadmap_PRTM.pdf
[65] Moore, G.A., "Crossing the Chasm", Harper Business Publishers, NY, NY (2002).
[66] Morton, J. A., "Organizing For Innovation: A Systems Approach to Technical Management", ISBN# 07-043420-4, McGraw Hill Publishers, New York, NY, 1971.
[67] Myers, S. and D. Marquis, D. "Successful Industrial Innovations", National Science Foundation, Report NSF 69-17, Washington DC (1969).
[68] Myers, S. and Sweezy, E. E., "Why Innovations Falter and Fail: A Study of 200 Cases", U.S. Department of Commerce, NTIS Report PB-159-108 (1976).

[69] National Research Council of the National Academies, "Accelerating Technology Transition: Bridging the Valley of Death for Materials and Processes in Defense Systems", National Academies Press, Washington DC, 2004, ISBN: 0-309-09317-1.

[70] National Research Council, "21st Century Innovation Systems for Japan and the United States: Lessons from a Decade of Change: Report of a Symposium Committee on Comparative Innovation Policy: Best Practice for the 21st Century; Sadao Nagaoka, Masayuki Kondo, Kenneth Flamm, and Charles Wessner, Editors; National Reserach Council ISBN: 0-309-11978-2, 302 pages, 2009, accessed from http://www.nap.edu/catalog/12194.html

[71] O'Connor, G.C. and R. DeMartino, *Organizing for Radical Innovation: An Exploratory Study of the Structural Aspects of RI Management Systems in Large Established Firms.* J. Prod. Innov. Manag., 2006. **23**(6): p. 475-497.

[72] Perez, C., *Technological revolutions and financial capital : the dynamics of bubbles and golden ages*. 2002, Cheltenham, UK ; Northampton, MA, USA: E. Elgar Pub.

[73] Petkovic, R. A., Dismukes, J. P., and Cohen, L. Y., "Science Based Accelerated Technological Innovation." *PICMET'99 Proceedings*, Portland, Oregon, July 1999.

[74] Prescott, J. E. , and Gibbons, P. T., "The evolution of competitive intelligence," *International Review of Strategic Management*, Vol. 6, 1995, pp. 71-90.

[75] Porter,.A. L. and Cunningham,, S. W., TECH MINING: Exploiting New Technologies for Competitive Advantage, John Wiley & Sons, Hoboken, NJ, 2005.

[76] Porter, A. L., "Tech Mining to Accelerate Radical Innovation*", PICMET 2007Proceedings, 2007, pp. 851-867.*

[77] Porter, M. E. and Millar, V. E., How Information Gives You Competitive Advantage, Harvard Business Review, July-August, pp. 149-160, 1985.

[78] Rich, Ben R., and Janos, Leo, "Skunk Works: A Personal Memoir of My Years at Lockheed, Little, Brown and Company, New York, NY (1994).

[79] Roberts, E. B., "Managing Invention and Innovation", Research-Technology Management, Volume 50, pp. 35-54, January – February, 2007. Note: *This article was first published in Research-Technology Management, Volume 31, pp. 11-29, 1985*.

[80] Roberts, E. B., "Generating Technological Innovation", ISBN# 0-19-505023-1, Sloan Management Review / Oxford University Press, Oxford, UK, 1987.

[81] Rogers, E. M., Diffusion of Innovations, 5th Edition, Free Press, New York, NY , 2003.

[82] Schoemaker, P.J.H. "Scenario Planning: A Tool for Strategic Thinking," Sloan Management Review, Winter 1995, pp. 25-40.

[83] Schoemaker, P. J.H. and van der Heijden, C. A. J. M., "Integrating Scenarios into Strategic Planning at Royal Dutch/Shell," *Planning Review*. Vol. 20 (3): 1992, pp.41-46.

[84] Schoemaker, P. J. H., "Multiple Scenario Developing: Its Conceptual and Behavioral Basis," *Strategic Management Journal*. Vol. 14: 1993, pp 193-213.

[85] Schumpeter, J. A., Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalistic Process, McGraw-Hill, New York, NY, 1939.

[86] Sekhar, J. A. and Dismukes, J. P., Generic Innovation Dynamics Across The Industrial Technology Life Cycle, Technological Forecasting and Social Change, 2008, 1016/j.techfore.2008.08.010.

[87] Shenhar, A. J., Dvir, D., and Shulman, Y., "A Two-Dimensional Taxonomy of Products and Innovations", J. Eng. Technol. Management Vol. 12, 175-200, 1995.

[88] Shenhar, A. J., "One Size Does Not Fit All Projects: Exploring Classical Contingency Domains", Management Science, Volume 47, No. 3, pp. 394-414, 2001.

[89] Stokes, D. E., "Pasteur's Quadrant: Basic Science and Technological Innovation," Brookings Institution Press, Washington D. C, 1997.

[90] Suh, Nam P., "A Theory of Complexity, Periodicity and Design Axioms", Research in Engineering Design, Volume 11, pp. 116-131 (1999).

[91] Suh, Nam P., "Complexity: Theory and Applications", Oxford University Press, Oxford, UK (2005).

[92] Utterback., J. M., Innovation in Industry and the Diffusion of Technology, Science, Vol. 183, No. 4125, Feb. 15, 1974.

[93] Utterback,. J. M., Mastering the Dynamics of Innovation, Harvard Business School Press, Cambridge, MA, 1994.

[94] Voss, C. A., The Need for a Field of Study of Implementation of Innovations, J. Prod. Innov. Management , Volume 4, pp. 266-271 (1985).

[95] Wack, Pierre, "Scenarios: Uncharted Waters Ahead", Harvard Business Review, Volume 63, September-October, pp. 73-99, 1985.

[96] Walton, K. R., Dismukes, J. P., and Browning, J. E., "An Information Specialist Joins the R&D Team." *Research Technology Management*, Vol 32, No. 5, 1989, pp. 32 – 37.

[97] Wenger, E. C. and Snyder, W. M., "Communities of Practice: The Organizational Frontier", Harvard Business Reviiew, January-February 2000, pp. 139-145, 2000.

[98] Womack, J. P. and Jones, D. T., Lean Thinking: Banish Waste and Create Wealth in Your Corporation", Simon and Schuster, New York, NY, 1996.

[99] Womack, J. P. and Jones, D. T., "Lean Solutions: How Companies and Customers Can Create Value and Wealth together", ISBN# 0-7432-7778-3, Simon and Schuster Publishers, New York, NY, 2005.

[100] Yang, K and Zhang, H., A Comparison of TRIZ and Axiomatic Design: Parts 1 and 2, in Compatibility Analysis and Case Studies of Axiomatic Design and TRIZ, September 2000.

APPENDIX I. SUMMARY OF THE 4 ARI GRAND CHALLENGES: ARI STEP 3

In Step 3 the innovator identifies the grand challenges that must be addressed to bring the radical innovation concept into being, to meet or exceed the market requirement, and to achieve its potential performance level. In conventional innovation processes, the innovator focuses on the scientific and technological domain, deferring consideration of market/societal and business and organizational challenges, but to accelerate the innovation process, ARI works by front-loading – identifying and pursuing all the key challenges, and their accompanying resource hurdles (people and financial), simultaneously and synergistically –and from the outset of the innovation cycle.

Market and Societal Challenges

Market challenges: Radical innovators inevitably will face competing approaches from other players. Before their technology can begin the period of rapid sales growth, a single dominant design must emerge from among the competing design approaches. This painful, Darwinian struggle (the Valley of Death) strongly favors the incumbent. And more technically conservative designs are five times as likely to prevail as more innovative ones. Innovators must be able to understand, engage in, and influence the social processes that result in the selection of dominant designs (e.g., negotiating industry or regulatory standards). For radical innovators, participation in this competitive arena is not optional!

Societal challenges: Assimilation of radical innovation also plays out on the larger societal stage. Industries, careers, jobs, financial investments, infrastructure, laws, regulations, and case law, academic disciplines, educational curricula, etc., are built around established traditions of practice. Practitioners, users, educators, support personnel, and the entire supporting professional community (accountants, lawyers, policymakers, investment analysts, etc.) may have to unlearn skills and processes that they have relied upon and undertake the arduous process of building new traditions of practice. This stage maps out the range of activities that need to be addressed.

Scientific and Technological Challenges

For radical innovations intended to break through technical, cost, or performance barriers, or to create an entirely new capability, identifying and resolving scientific and technological challenges is at the heart of the innovation process. Overcoming scientific and technical challenges is likely to consume the greatest proportion of time and cost, and poses some of the highest risks to the innovator. Given the tendency of technical efforts to assume a life of their own, the innovator uses this step to tightly define the technology development objectives and processes around target requirements of performance, reliability, cost, and manufacturability.

Business and Organizational Challenges

Bringing a breakthrough innovation concept to technical maturity and (particularly) commercial realization cannot be left to a few individuals – it requires the strong leadership and sustained stewardship of a committed organization. Investors recognize that even the best innovation concepts will encounter serious unanticipated challenges during the development and commercialization stages, but they are willing to invest anyway if they are convinced that strong leadership and a strong organization are in place to address them. In this section, the innovator identifies the key business and organizational resources and capabilities needed to support a successful innovation, and assesses how well his/her own organization is positioned.

Cluster and Network Challenges

Bringing a radical innovation to fruition usually requires a more diverse set of capabilities and resources than any single company or organization possesses. And if the innovation disrupts the organization's established business model, the organization is more likely to resist it than support it. The ARI model applies the concept of "open innovation," where organizations reach beyond their boundaries to acquire intellectual property they need or to spin innovations out to other organizations where the strategic fit is better, or even launching entirely new organizations. ARI takes the open innovation concept one step further: identifying and engaging *all* the innovation's potential stakeholders and affected constituencies in the user, industrial, and public communities. By building these stakeholders and constituencies into the innovation process at the front end, the innovator can incorporate their needs and concerns into the innovation process from the outset, minimize subsequent market resistance and accelerate acceptance and deployment.

APPENDIX II. AN INNOVATION ATTRIBUTE EXAMPLE FOR ARI MANAGEMENT

The 10 essential innovation attributes (Figure 7 and Figure 8, Section 3) provide a framework for assessing innovation development at each Step in the ARI Methodology Process. Although only one Innovation Attribute is here addressed, as an example, because of limitation of space of this paper, our future objective is to provide access to all 10 Innovation Attributes.

The Innovation Attribute Framework has the following benefits for developing a quantitative and qualitative scorecard to measure progress, and to guide radical innovation commercialization activities. The intrinsic benefits of this framework include:

- Allow a breakthrough innovation team to discover, assess and flesh out the status of their proposed breakthrough radical innovation at each of the 10 ARI Steps from inception to implementation.

- Provide a set of questions for each attribute that will enable the team to pinpoint their progress in advancing the innovation with respect to each Attribute at each Step.
- Describe a set of "innovation states" representing the degree of progress of the innovation team at that point of time, and pointing the way to applying competitive intelligence tools to obtain concrete information upon which to develop a business plan as a key milestone for ARI Step 6. This includes the business model adopted for the innovation, and a commercialization roadmap for advancing the innovation through ARI Steps 7-10 to achieve commercialization of a Standard Design.

For Innovation Attribute 4, Innovation Design, a definition and brief discussion is provided below, followed by tablulation of that attribute's Progress Status Questions and Progress Status States providing generic answers to the Progress Status Questions.

Innovation Attribute 4. Innovation Design

Definition: Feasibility and maturity of design, development and technological and system performance of the integrated product, process, software or service. Seven typical sub-factors related to an Innovation Design are listed below, followed by Tables for Progress Status Questions and Progress Status States.

4.1 Performance. A prerequisite for a major innovation to be accepted by its intended market is an acceptable level of performance on parameters that matter to the market. Performance parameters will vary, depending on the industry or technological discipline to which the innovation belongs.

4.2 System Design. Before they can be fully implemented, most innovations must be embedded in a system of interworking elements, some of which already may be in place or available, others of which must be developed. Moreover, these elements must be linked into an overall system architecture to ensure they work smoothly together as intended and as required by the user community**.**

4.3 Feasibility. An innovation can meet its performance requirements in principle but for a wide variety of reasons may turn out to be practically infeasible when put into practice. Reasons may include cost, size, weight, energy consumption, dependence on external elements that are infeasible or uneconomical, and difficulty of application in a standard operating environment.

4.4 Cost Considerations. Cost acceptable to identified customers is an essential sub-attribute here. Many radical innovations are ready in all aspects but cost – but cost is a showstopper (e.g. wind energy, fuel cells, advanced biofuels, drugs for orphan diseases). Cost may be acceptable or unacceptable based on the value a market believes it will receive (and that value may value from one market to another) or on the cost of comparable solutions to the same user need (competing versions or alternative solutions).

4.5 Ease of use. Even for innovations that are otherwise feasible, practitioners (end users, operators, support personnel, etc.) may have to take considerable time learning to apply the innovation before they are proficient. Particularly if users have taken a long time to reach proficiency in a different approach, it may be difficult to persuade them to make the sacrifice. At the extreme, it isn't practicable to retrain current practitioners; a new practice area must be created.

4.6 Standardization of Design. It is now well documented that mainstream adopters will not commit to an innovation until a standard design emerges from the variety of alternative concepts that emerge during the early stages of innovation. They fear being stranded if they place their bets on the wrong horse. Accordingly, for many technologies, only one design will survive in the marketplace, the so-called dominant design. For example, there is only one surviving standard design for the laptop computer – even the Macintosh, the most "different" laptop, is extremely similar to laptops based on the Windows operating system in form, function, and performance.

4.7 Maturity. Technological maturity is concerned with the shake-out of the innovation in the operational environment – the cumulative resolution of the myriad of unforeseen issues that inevitably arise as an innovation moves into practice. Over the course of its use, it can be expected that costs will come down, processes will be simplified, and designs will be improved, reducing the costs and risks of adoption for future practitioners.

Progress Status Questions for Innovation Attribute 4: Innovation Design

(Progress Status Questions 4.1 to 4.10 below tailored to determine the innovation team status in understanding their innovation with respect to the "innovation design")

Progress Status Question	Questions 4.1 to 4.10 below tailored to determine the innovation team status in understanding their innovation with respect to the "innovation vision".
4.1	Have all the applicable performance parameters for this innovation category been determined from customer interaction?
4.2	How close is the proposed innovation concept to meeting the market requirement on the applicable performance parameters.
4.3	Can these requirements be met within the cost, production and distribution time achievable by the innovation value network?
4.4	Has the innovation been developed into an innovation *system* with required elements linked into a working architecture?
4.5	Are alternative system designs required and are they consistent with standard manufacturing and distribution capabilities of the value chain partners, with industrial and governmental standards, and the collective performance and cost requirements of all the market segments?
4.6	Have feasibility of system design, from initial deployment, through its service life, and at the end of its service life (disposal) been considered and evaluated during accelerated innovation prototyping and test marketing of individual prototype designs?
4.7	Has it been verified through customer interaction that total system costs for the innovation are acceptable to the market?
4.8	Based on ease of use considerations, have the various customer segments made a firm commitment to a standard design appropriate to their particular application?
4.9	How close is the proposed innovation concept to meeting the market requirement for standardization of design addressing all envisioned market segments?
4.10	How close has the innovation come to maturity, taking into consideration life cycle cost, reliability, and ease of use in its intended operating environment?

Progress Status States for Innovation Attribute 4: Innovation Design

(Progress Status States represent current innovation team capability to answer Progress Status Questions 4.1 to 4.10 above)

Progress Status States	Current capability to answer Progress Status Questions 4.1 to 4.10 above
4.1	*Innovation Concept Defined.* At this stage, a crisis (market failure, exogenous natural or man-made crisis, change in social practice) or opportunity (scientific or technological breakthrough in the innovation domain) has been recognized, and a concept of how the envisioned innovation system will address the crisis/opportunity has been defined.
4.2	*Customer Requirements Defined.* Based on customer/stakeholder input, originating requirements for the innovation have been established.
4.3	*Design Requirements Defined.* Based on the originating (stakeholder) requirements, system requirements (specifications) have been determined.
4.4	*Innovation Functional Architecture Determined.* Based on the system requirements, a functional architecture and functional decomposition have been completed.
4.5	*Proof of Concept Established.* The innovation has been demonstrated to work at the proof-of-concept level (through theoretical analysis, laboratory demonstration, or computer simulation).
4.6	*Innovation Physical and Operational Architecture Determined.* Design has proceeded to include a complete physical and operational architecture down to the individual element level.
4.7	*System-Level Vision Defined.* The supporting technologies, complementary assets, and infrastructure required for market adoption have been determined.
4.8	*Value Network Defined.* The stakeholders needed to collaborate on commercializing the system-level vision have been identified, and the necessary collaborative relationships have been established.
4.9	*Pilot Projects Completed.* Remaining technical and market uncertainties (performance issues, reliability concerns, market acceptance, etc.) have been identified, and small-scale projects (field tests, simulations, etc.) have been launched to resolve them.
4.10	*Standard Design Established.* Based on field-test results, a standard design has been established, and all design issues prior to launch have been resolved.