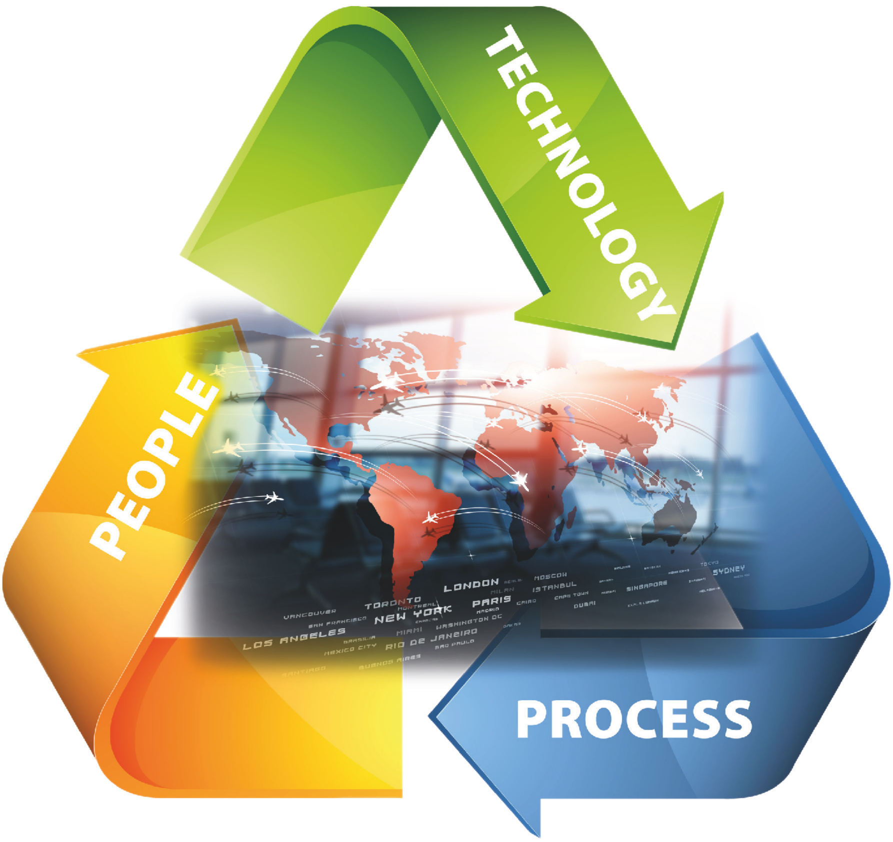
DEFENSE INNOVATION HANDBOOK

GUIDELINES, STRATEGIES, AND TECHNIQUES



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Defense Innovation Handbook

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Dedication

To Innovation, in all its diverse ramifications

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Foreword

I was asked by my good friends and colleagues Dr. Adedeji B. Badiru and Dr. Cassie B. Barlow who are contributing authors, compilers, and collaborating editors on this *Defense Innovation Handbook* you're reading to consider writing a Foreword "on the importance of Innovation to the DoD." I thought about it for a bit and sent Dr. Barlow a note back stating I wrestle with the term "innovation" in the DoD and in the tech community at large—much overused, not understood, too much money dumped in its name down the drain .... sooooooooooo not sure I'm your "Foreword" writer...... To which Dr. Barlow replied, "we actually completely agree that the term 'innovation' is overused and not well understood. That is exactly the reason why we wanted to pull the handbook together." If you're reading this, you see I acquiesced and decided with the above exchange to put a few thoughts together and share in this Foreword.

Dr. Badiru and Dr. Barlow are two of the finest, most giving and passionate people I know who work diligently every day to advance the end-state capabilities of our Department of Defense. From sharing their vast knowledge in the academic environment with students of all ages; to being staunch contributors to K-12 STEM programs; to leading regional workforce development in support of the Aerospace enterprise; and, most recently, seeing a chasm between the needs of the Department of Defense and how that "chasm" supposedly is being addressed in the name of "innovation" ..... yet knowing that there is a fundamental disconnect in the term, the risk levels and willingness of our DoD to truly allow "innovation" in fact to occur, decided to undertake the development of this handbook.

My personal belief is that the term "innovation" is overused in our technological communities. I find it to be a "label" placed on what perhaps is a good, maybe even solid, technical concept to fundamentally sell the idea to decision makers, who themselves would never stand in the way of something "innovative" and end up supporting an idea as innovative, but the idea actually provides no value. After all, who would want to be seen as standing in the way of innovation? Sadly, most don't seek the basic understandings of what is "innovative" in the context of what is being proposed and sold to them. In most simplistic terms I believe a run through of the Heilmeier Catechism would quickly separate the wheat from the chaff and help leaders and the Department to truly know whether a concept or idea is technologically sound, adds value and is truly "innovative."

The Catechism: (1) In the most simplistic terms what are you trying to do and why? (2) How is it done today and what are the limits of current practice? (3) What is new in your approach and why do you think it will be successful? Who cares? (4) If you are successful, what difference will it make? (5) What are the risks? (6) How much will it cost? (7) How long will it take? (8) What are the mid-term and final "exams" to check for success?

So, you've read this far and are possibly thinking, okay all fine and dandy, Joe, I passed all the gates laid out above... now what? Several years ago, many of us in the Dayton, Ohio region invited Dr. John Kao to come work with a large cross section of the Dayton Regional leadership. We spent a few days looking at exactly the issue of innovation and what had to happen to bring to fruition the world's truly innovative capabilities, such as powered flight; refrigeration; all electric starting, ignition and lighting for automobiles; cellophane tape; the step ladder; and traffic lights; to name a few.

Along with the innovation came a solid 100 years of prosperity in the industries that spawned the automotive, military, and civil aviation products which provided our USAF unparalleled air, space and cyber superiority. So, what was it that caused these advancements to occur? Several things in my mind. First it was a full-contact, hands-on sport, the people behind these great technological advancements had callouses and dirty fingernails, and worked shoulder-to-shoulder to solve the wicked problems of their day. No PowerPoint slides or Keynote involved. As we studied this with Dr. Kao, we understood that the inventors and innovators whose shoulders we stand on worked tirelessly to "convert possibilities into value." They were not focused on the world's definition of value around wealth-based tangible assets, but value in terms of the capability to continuously realize the future they wanted. It wasn't about money, it was about enhancing the quality of life, advancing the body of knowledge, advancing capabilities, especially in the DoD, where we, to this day, seek to have an unfair technological advantage over our near-peer adversaries. Scientists, engineers, inventors, and lay people saw a future and went after it.

So, were they Innovators?

I submit to you—yes, based on the following unwrapping of innovation by Dr. Kao. "Innovation a (noun) + a (verb)—The portfolio of financial, intellectual, organization and human capabilities that enable a society's journey to its desired future." Innovation occurs across a value chain; innovation then is an idea followed by a reasoned complementary or juxtaposed action; Science and Art; Engineering and Design; Incremental and Disruptive; Inside Out and Outside In; Public and Private; Left Brain and Right Brain; Analytics and Values; Facts and Possibilities; Risk Taking and Prudence; Inspiration and Planning; Closure and Treasure Hunting. The sum then of innovation is agility, foresight, enlightened leadership, risk appetite, and the appetite for experimentation.

As you step forward to "convert possibilities into value" heed the words of this Foreword and the compendium of thought leadership that is contained in this DoD Handbook. Thank you for your Service to this great Nation, be it in uniform, as a civilian, an academician, or a defense contractor. Above all else, remember our US Military, Allied and Coalition partners require the best of the best, 210% reliable in every off-nominal condition you can't even imagine—so, yes, be innovative, be realistic and yet please be humbled enough to understand that though you may have thought up the greatest innovative thing since sliced bread, it may have no place in the DoD inventory.

Joe Sciabica, SES Retired
President, Universal Technology Corporation
Dayton, Ohio

Preface

"Innovation" is one of the most recognized and most used words, not only in the defense enterprise, but also in many science and technology realms. Indeed, it is also frequently cited in business and industry. When people talk of innovation, their term of reference is usually technological developments. But innovation goes well beyond the technical realm. Innovation in process and strategies is just as important and relevant as technological developments. Many times, process and business innovations are even more important than technological innovations because the manifestation of technology can be realized only through effective processes and strategies. The *Defense Innovation Handbook: Guidelines, Strategies, and Techniques* represents a monumental collection of diverse views of innovation, from technological requirements to process and managerial requirements. Specific themes addressed by the 23 chapters in the handbook include "Innovation for national defense," "Definitional analysis of innovation," "The aerospace and defense industry in Southwest Ohio: A model for workforce-driven economic development," "Other transactions: Increasing importance in the Department of Defense," "Commercial technologies in the Department of Defense: Technology evolution and implications for acquisition professionals," "A system and statistical engineering enabled approach for process innovation," "Building resilient systems via innovative human systems integration," "Innovative model for situation awareness in dynamic defense systems," "Globalization and defense manufacturing," "Is your organization ready for innovation?" "Human monitoring systems for health, fitness and performance augmentation," "Enhancing innovation: Methods, cultural aspects, ideation approaches, and box busters," "Self-jamming behavior: Joint interoperability, root causes, and thoughts on solutions," "4D Weather Cubes and defense applications," "Innovative approach to infrastructure resilience: A case study of evaluating Department of Defense sites for small modular reactors," "Three innovations for defense acquisition reform," "Strategy and military technology: The three offsets," "Prescription for an affordable full spectrum defense and innovation policy," "Anatomy of arms races and technological innovation," "Innovation dynamics in the defense space sector," "Innovative applications of polymer materials for 3D printing," "Innovation project management," and "Innovation in systems framework for intelligence operations." With this collection of diverse and thought-provoking chapters, all readers will find this handbook to be a useful reference at home, work, industry, education, and business environments. Please join us in innovative thought!

Acknowledgments

We acknowledge Ms. Anna E. Maloney for her extraordinary contributions to this monumental handbook. Not only did she serve as a co-author of one of the chapters, but she also provided superior editorial and administrative support for the book project from the beginning to the end. Her insightful suggestions and technical finessing of the chapters greatly increased the overall quality of the handbook. Without her consistent dedication to the project, the handbook would not have been completed on time.

Editors

Dr. Adedeji B. Badiru is a Professor of Systems Engineering at the Air Force Institute of Technology (AFIT). He is a registered professional engineer and a fellow of the Institute of Industrial Engineers as well as a fellow of the Nigerian Academy of Engineering. He earned a BS in Industrial Engineering, MS in Mathematics, and MS in Industrial Engineering from Tennessee Technological University, and PhD in Industrial Engineering from the University of Central Florida. He is the author of several books and technical journal articles. Prof. Badiru has served as a consultant to several organizations around the world including Russia, Mexico, Taiwan, Nigeria, and Ghana. He has conducted customized training workshops for numerous organizations including Sony, AT&T, Seagate Technology, US Air Force, Oklahoma Gas & Electric, Oklahoma Asphalt Pavement Association, Hitachi, Nigeria National Petroleum Corporation, and ExxonMobil. He holds a leadership certificate from the University Tennessee Leadership Institute. Prof. Badiru has served as a Technical Project Reviewer, curriculum reviewer, and proposal reviewer for several organizations including The Third-World Network of Scientific Organizations, National Science Foundation, National Research Council, and the American Council on Education. He is on the editorial and review boards of several technical journals and book publishers. Prof. Badiru has also served as an Industrial Development Consultant to the United Nations Development Program. He is also a Program Evaluator for ABET. In 2011, Prof. Badiru led a research team to develop analytical models for Systems Engineering Research Efficiency (SEER) for the Air Force acquisitions integration office at the Pentagon. He has led a multi-year composite manufacturing collaborative research between the Air Force Institute of Technology and Wyle Aerospace Company. Prof. Badiru has diverse areas of avocation. His professional accomplishments are coupled with his passion for writing about everyday events and interpersonal issues, especially those dealing with social responsibility. Outside of the academic realm, he writes motivational poems, editorials, and newspaper commentaries; he also engages in paintings and crafts.

Dr. Cassie B. Barlow is the Chief Operating Officer at the Southwestern Ohio Council for Higher Education. Her focus is on developing the defense workforce of the next generation. Previously, she was the 88th Air Base Wing and Installation Commander, Wright-Patterson AFB, Ohio, where she was in command of one of the largest air base wings in the Air Force with more than 5,000 Air Force military and civilian employees. Dr. Barlow was commissioned in 1988 as a distinguished graduate of Georgetown University, Washington, DC. She has served in a variety of positions in the information management, behavioral science and personnel career fields at squadron, Wing, direct reporting unit, major command, Air Force and combatant command levels. Dr. Barlow was selected by the Air Force Institute of Technology to attend Rice University to earn a doctorate in Organizational Psychology. After graduation, she served as a behavioral scientist at the Air Force Research Laboratory and the Air Force Academy. She was then selected to lead the analysis team for the Chief of Staff of the Air Force Developing Aerospace Leaders Program. Dr. Barlow commanded the 355th Mission Support Squadron at Davis Monthan Air Force Base, Arizona, and the 48th Mission Support Group at Royal Air Force Lakenheath. She was also the Director of Manpower and Personnel of the North American Aerospace Defense Command and United States Northern Command, headquartered at Peterson Air Force Base, Colorado. Dr. Barlow attended the Air Command and Staff College and the Industrial College of the Armed Forces.

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chapter one

Innovation for national defense

Adedeji B. Badiru

Contents

> Innovation: Give it to someone who can make something of it or keep it to yourself and make nothing of it.
>
> **Adedeji Badiru, 2018**
>
> Collaboration is the essence of actualizing innovation for practical applications as opined by the quote above.

Introduction

Evolution, revolution, and innovation have defined human existence for millennia. From the Ice Age to the Stone Age, the Bronze Age, the Iron Age, and the modern age, innovation, rudimentary as it may be in many cases, has determined how humans move from one stage to the next. Innovation is the lifeline of national development. This handbook presents a collection of chapters that provide techniques and methodologies for achieving the transfer of defense-targeted science and technology development for general industrial applications. Experts from national defense institutions, government laboratories, business, and industry contributed chapters to the handbook. The handbook provides a lasting guidance for nations, communities, and businesses expecting to embark upon science and technology transfer to industry under the auspices of national defense pursuits. We don't often make a connection between a viable industrial base and a robust national defense. The fact is that a vibrant base of industrial activities can promote and protect national defense pursuits, particularly where economic vitality is concerned.

There is a need for a good utility framework for this handbook because of the globalization of modern industries desirous of capitalizing on technical developments in the defense industry for the purpose of developing new consumer products. Many nations are interested in embarking on rapid prototyping of new technologies from their defense organizations for the advancement of their nations. Guidelines, strategies, and techniques are needed to actualize their aspirations. Allied nations often conduct joint defense exercises, the coalitions from which can advance their respective local industries. Some good examples of how national defense products enhance general consumer products include the following:

1. There are several consumer products that originated from initial defense focus, such as the microwave oven and the global positioning system (GPS).
2. R&D personnel from defense organizations often end up working in general business and industry, where their expertise is needed through consumer technology transfer processes.
3. The International Space Station combines the efforts of cooperating nations, thus paving the way for potential advancement of tech-transfer industries at the national level.
4. Many formerly classified defense-related developments have been declassified, thereby necessitating the need for tech transfer strategies to industry.

The overall conclusion is that a strong national defense program fuels a strong industrial base. Every country, even the poorest ones, must be engaged in national defense pursuits, which are predicated on innovation, both soft and hard. Not all innovation is of a technical breed. Soft innovation may pertain only to the processes and managerial principles for managing and deploying innovation. Hard innovation may relate to technical and technology-based developments that enhance the focus on national defense.

Digital revolution and innovation

The digital environment has created new opportunity for new innovation developments both in technology and in operational processes. For example, in the digital emergence of 3D printing (additive manufacturing), the lead editor offers the following operational quotes:

> "Little thoughts make up big ideas."
>
> **—Adedeji Badiru**

> "Big components are made in little layers of material."
>
> **—Adedeji Badiru**

Manufacturing is rapidly shifting from manual labor to digital labor. The digital revolution has landed on the doorstep of conventional manufacturing. What was once limited to the realm of laboratory research has now been transformed, through innovation, to the platform of practicality and reality. For decades, manufacturing had languished within the same old framework of mold-and-cast type of product development. This traditional approach has made manufacturing subject to the inability to respond quickly and adaptively to new product requirements. With the advent of direct digital manufacturing (aka 3D printing or additive manufacturing), product designers and developers now have a mechanism to respond to the requirements for new intricately designed and delivered products, often at the immediate point of need. The defense sector is well positioned to leverage the capabilities of this new digital innovation for designing and making products. The emerging proliferation of 3D printing in business and industry has made it imperative that a structural forum be organized to guide the path of full utilization of innovative developments in digital manufacturing. The conventional product development environment is vastly different from what 3D printing will require. Hitherto, individuals and organizations have been jumping on the 3D printing bandwagon without strategic consideration of downstream and upstream aspects of "printed" products. This handbook forum offers a structured platform of enabling innovation in the defense sector. Both technical and management issues related to this new wave of innovation are addressed in the handbook. The expected benefits of innovation dialogue and exchanges include a better alignment of product technology with future developments and the need to secure, maintain, and advance national defense. Specifically, readers of this handbook will learn about the systems engineering aspect of 3D printing to achieve a faster translation of innovation into real products as well as operational effectiveness, raw material efficiency, higher return on manufacturing investment, rapid and focused product deployment, technology transfer potentials, manufacturing flexibility, and anywhere-anytime agility for product generation.

With the additional emergence of virtual reality (VR), augmented reality (AR), and mixed reality (MR), the platform of innovation for the defense industry is growing rapidly. These emerging technologies can be leveraged to provide cost-effective development of new products. The best way to accomplish this is to mix innovation and collaboration.

Central role of innovation

The central role of innovation in national defense is evidenced by the fact that "Drive Innovation" is one of the top five priorities announced by the US Air Force in August 2017. The priorities, released by USAF secretary Heather Wilson, are

1. Restore readiness
2. Cost-effectively modernize
3. Drive innovation
4. Develop exceptional leaders
5. Strengthen alliances

Figure 1.1 shows the cross-linkages of the five priorities and how innovation has a central role. We cannot restore readiness without employing new innovative tools and techniques. We cannot cost-effectively modernize without developing and utilizing radically innovative quantitative and qualitative methodologies. We cannot develop exceptional leaders without directing efforts at new, innovative, and specialized education, including advanced education. We cannot strengthen alliances without innovative partnering strategies. In a systems approach, a system is defined as the collection of interrelated elements whose collective output is higher than the sum of the individual outputs of the elements. As a specific tool, the DEJI® (Design, Evaluation, Justification, and Integration) model of systems engineering is unique and innovative because it explicitly calls for a ***justification*** and ***integration*** of actions, which requires a more rational decision process during the ***design*** and ***evaluation*** stages. The model facilitates a recursive *design-evaluate-justify-integrate* process for enhancing

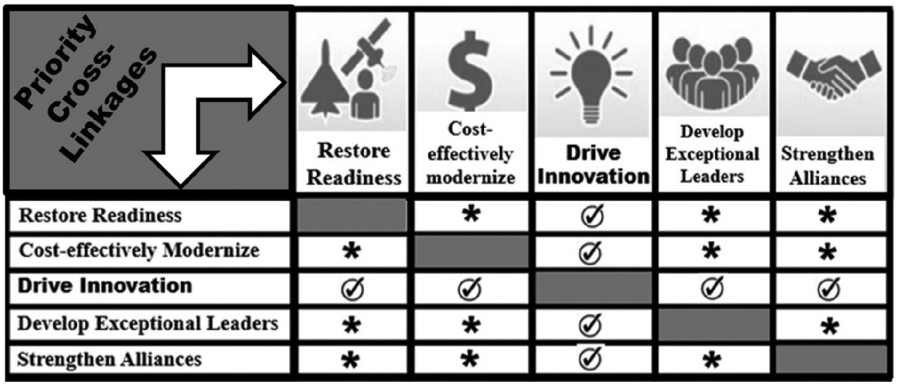

Figure 1.1 Central role of innovation in air force priority cross-linkages. ✓ Innovation Alignment across priorities and ✱ Inter-priority alignment.

operations. The design stage is essentially the decision stage, which must be evaluated and justified before moving to the implementation stage. The typical implementation stage must be pursued with respect to how well the decision (i.e., design) integrates into the prevailing infrastructure and resource base of the organizations involved. Thus, the model covers the broad spectrum of people, process, and technology in national defense pursuits. Some of the analytical tools used in the DEJI model include state-space modeling, simulation, systems value modeling, learning curve analysis, workload analysis, cognitive modeling, and hierarchical decision transformation. The DEJI model is further discussed later in this chapter. Based on a systems approach, priorities are best pursued from a system of systems perspective. In this regard, multifaceted collaboration approaches must be embraced.

Multifaceted collaboration for innovation

Innovation is best pursued via multifaceted collaboration. No one entity has all the answers. Together, innovation is stronger. Figure 1.2 shows a framework for academia-government-industry collaboration that can be leveraged for the pursuit and sustainment of innovation.

In executing the desired multifaceted collaboration for innovation, some of the technical topics of interest include, but are not limited to, the following:

- Hypersonic weaponry
- Stealth technology
- Autonomous systems
- Mobile radar platforms
- Directed energy systems
- Laser warning systems
- Cognitive radio networks
- Human performance systems
- Quantum computing
- Neuromorphic computing
- Additive manufacturing
- CUBESAT (Cube Satellite), a type of miniaturized satellite for space research that is made up of multiples of 10×10×10 cm cubic units (U-Class Spacecraft) and conventional satellite technology
- Artificial intelligence and machine learning

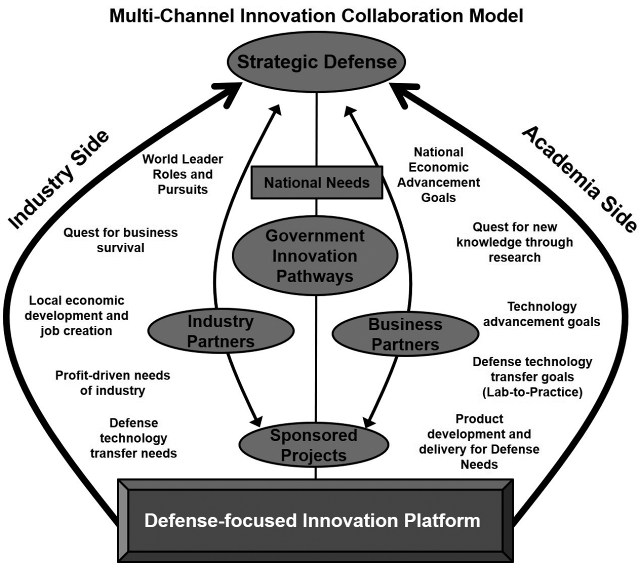

Figure 1.2 Framework for multifaceted defense-focused innovation.

There are several complementary and auxiliary topics affiliated with the earlier list. In addition to the technological aspects of innovation, there are also issues of human-centric innovation as well as process innovations, such as logistics and integrated supply chain, to get the mission done in contested environments. Thus, the span of innovation is quite expansive.

Innovation transfer paths

Just as we may have technology transfer paths, so can we have innovation transfer paths.

Innovation transfer is not just about the hardware, technology, or technical components of a system. It can involve a combination of several components, including software (computer-based) and peopleware. Thus, this chapter addresses the transfer of innovation knowledge as well as the transfer of innovation skills.

Due to its many interfaces, the area of technology adoption and implementation is a prime candidate for the application of project planning and control techniques. Technology managers, engineers, and analysts should make an effort to take advantage of the effectiveness of project management tools. This applies the various project management techniques available to the problem of innovation transfer. The project management approach is presented within the context of innovation adoption and implementation for national defense. The Triple C model of Communication, Cooperation, and Coordination is applied as an effective tool for ensuring the acceptance of new innovation products.

Characteristics of innovation transfer

To transfer innovation, like any technology transfer, we must know what constitutes innovation. A working definition of innovation will enable us to determine how best to transfer it. A basic question that should be asked is: What is innovation?

Innovation can mean different things to different audiences. Innovation can be defined as follows:

Innovation is a combination of physical and nonphysical processes that make use of the latest available knowledge, skills, technology, etc. to achieve business, service, or organizational goals.

Innovation is a specialized body of knowledge that can be applied to achieve a mission or purpose. The knowledge concerned could be in the form of methods, processes, techniques, tools, machines, materials, and procedures. Technology design, development, and effective use is driven by effective utilization of human resources and effective management systems. Technological progress is the result obtained when the provision of technology is used in an effective and efficient manner to improve productivity, reduce waste, improve human satisfaction, or meet specific operational needs.

Innovation all by itself is useless. However, when the right innovation is put to the right use, with effective supporting management systems, it can be very effective in achieving organizational goals. Innovation implementation starts with an idea and ends with a productive process. Innovative progress is said to have occurred when the outputs of innovation, in the form of information, instrument, or knowledge that is used productively and effectively in industrial operations, leads to a lowering of costs of production, better product quality, higher levels of output (from the same amount of inputs), and better alignment with mission requirements. The information and knowledge involved in innovation progress includes those which improve the performance of management, labor, and the total resources expended for a given activity.

Innovation progress plays a vital role in improving overall national defense. Experience in the developed countries, such as the United States, show that in the period 1870–1957, 90% of the rise in real output per man-hour can be attributed to technological progress fueled by innovation. It is conceivable that a higher proportion of increases in per capita income is accounted for by technological change. Changes occur through improvements in the efficiency in the use of existing technology; that is, through learning and through the adaptation of other technologies, some of which may involve different collections of technological equipment. The challenge to developing countries is how to develop infrastructure that promotes, uses, adapts, and advances technological knowledge.

Most of the developing nations today face serious challenges arising not only from the worldwide imbalance of dwindling revenue from industrial products and oil, but also from major changes in a world economy that is characterized by competition, imports, and exports of not only oil, but also of basic technology, weapon systems, and electronics. If technology utilization is not given the right attention in all sectors of the national economy, the much-desired national defense cannot occur or cannot be sustained. If innovation is stymied, the ability of a nation to compete in the world market will, consequently, be stymied, with potential adverse implication for national defense.

The important characteristics or attributes of a new technology may include productivity improvement, improved quality, cost savings, flexibility, reliability, and safety. An integrated evaluation must be performed to ensure that a proposed technology is justified both economically and technically. The scope and goals of the proposed technology must be established right from the beginning of the project. Table 1.1 summarizes some of the common "ilities" characteristics of innovation transfer assessment.

An assessment of a technology transfer opportunity will entail a comparison of unit-level objectives with the overall organizational goals in the following areas.

1. *Marketing and outreach strategy*: This should identify the customers of the proposed technology. It should also address items such as market cost of proposed product, assessment of competition, and market share. Import and export considerations should be a key component of the marketing strategy.

Table 1.1 The "ilities" assessment of innovation

Characteristics	Definitions, questions, and implications
Adaptability	Can the technology be adapted to fit the needs of the organization? Can the organization adapt to the requirements of the technology?
Affordability	Can the organization afford the technology in terms of first-cost, installation cost, sustainment cost, and other incidentals?
Capability	What are the capabilities of the technology with respect to what the organization needs? Can the technology meet the current and emerging needs of the organization?
Compatibility	Is the technology compatible with existing software and hardware?
Configurability	Can the technology be configured for the existing physical infrastructure available within the organization?
Dependability	Is the technology dependable enough to produce the outputs expected?
Desirability	Is the particular technology desirable for the prevailing operating environment of the organization? Are there environmental issues and/or social concerns related the technology?
Expandability	Can the technology be expanded to fit the changing needs of the organization?
Flexibility	Does the technology have flexible characteristics to accomplish alternate production requirements?
Interchangeability	Can the technology be interchanged with currently available tools and equipment in the organization? In case of operational problems, can the technology be interchanged with something else?
Maintainability	Does the organization have the wherewithal to maintain the technology?
Manageability	Does the organization have adequate management infrastructure to acquire and use the technology?
Re-configurability	When operating conditions change or organizational infrastructure change, can the technology be re-configured to meet new needs?
Reliability	Is the technology reliable in terms of technical, physical, and/or scientific characteristics?
Stability	Is the technology mature and stable enough to warrant an investment within the current operating scenario?
Sustainability	Is the organization committed enough to sustain the technology for the long haul? Is the design of the technology sound and proven to be sustainable?
Volatility	Is the technology devoid of volatile developments? Is the source of the technology devoid of political upheavals and/or social unrests?

2. *Industry growth and long-range expectations*: This should address short-range expectations, long-range expectations, future competitiveness, future capability, and prevailing size and strength of the industry that will use the proposed technology.
3. *National defense benefit*: Any prospective technology must be evaluated in terms of direct and indirect benefits to be generated by the technology. These may include product price versus value, increased international trade, improved standard of living, cleaner environment, safer work place, and higher productivity.
4. *Economic feasibility*: An analysis of how the technology will contribute to profitability should consider past performance of the technology, incremental benefits of the new technology versus conventional technology, and value added by the new technology.
5. *Capital investment*: Comprehensive economic analysis should play a significant role in the technology assessment process. This may cover an evaluation of fixed and sunk

costs, cost of obsolescence, maintenance requirements, recurring costs, installation cost, space requirement cost, capital substitution options, return on investment, tax implications, cost of capital, and other concurrent projects.

6. *Innovation resource requirements*: The utilization of resources (human resources and equipment) in the pre-technology and post-technology phases of industrialization should be assessed. This may be based on material input-output flows, high value of equipment versus productivity improvement, required inputs for the technology, expected output of the technology, and utilization of technical and nontechnical personnel.
7. *Innovation technology stability*: Uncertainty is a reality in technology adoption efforts. Uncertainty will need to be assessed for the initial investment, return on investment, payback period, public reactions, environmental impact, and volatility of the technology.
8. *National defense improvement*: An analysis of how the technology may contribute to national productivity may be verified by studying industrial throughput, efficiency of production processes, utilization of raw materials, equipment maintenance, absenteeism, learning rate, and design-to-production cycle.

Embracing new innovation

Opportunity lost can be a recurring risk in industry. When new innovation knocks, it should be embraced. A good case example of opportunity lost and innovation ignored is the case of digital photography first developed (and ignored) at Kodak in the mid-1970s. Kodak ignored the new innovation, perhaps because it conflicted with their traditional market model. In 1998, Kodak had 170,000 employees and sold 85% of all photo paper worldwide. Within just a few years, Kodak's business model disappeared and the company went out of its traditional business. Had Kodak aggressively embraced and leveraged the new digital photography in 1975, the future of the company might have taken a different positive and profitable path. If innovation is not timely embraced and capitalized on, what happened at Kodak can happen to many other companies in the prevailing digital engineering and manufacturing environment, particularly those dealing with artificial intelligence, health, autonomous and electric cars, (Science, Technology, Engineering, Mathematics [STEM]) education, 3D printing, agriculture, and knowledge-based jobs.

Fortunately, new industrial and service technologies have been gaining more attention in recent years. This is due to the high rate at which new productivity improvement technologies are being developed. The fast pace of new technologies has created difficult implementation and management problems for many organizations. New technology can be successfully implemented only if it is viewed as a system whose various components must be evaluated within an integrated managerial framework. Such a framework is provided by a project management approach. A multitude of new technologies has emerged in recent years. It is important to consider the peculiar characteristics of a new technology before establishing adoption and implementation strategies. The justification for the adoption of a new technology is usually a combination of several factors rather than a single characteristic of the technology. The potential of a specific technology to contribute to industrial development goals must be carefully assessed. The technology assessment process should explicitly address the following questions:

What is expected from the new technology?
Where and when will the new technology be used?
How is the new technology similar to or different from existing technologies?

What is the availability of technical personnel to support the new technology?
What administrative support is needed for the new technology?
Who will use the new technology?
How will the new technology be used?
Why is the technology needed?

The development, transfer, adoption, utilization, and management of technology is a problem that is faced in one form or another by business, industry, and government establishments. Some of the specific problems in technology transfer and management include the following:

- Controlling technological change
- Integrating technology objectives
- Shortening the technology transfer time
- Identifying a suitable target for technology transfer
- Coordinating the research and implementation interface
- Formally assessing current and proposed technologies
- Developing accurate performance measures for technology
- Determining the scope or boundary of technology transfer
- Managing the process of entering or exiting a technology
- Understanding the specific capability of a chosen technology
- Estimating the risk and capital requirements of a technology

Integrated managerial efforts should be directed at solving the problems stated earlier. A managerial revolution is needed in order to cope with the ongoing technological revolution. The revolution can be initiated by modernizing the long-standing and obsolete management culture relating to technology transfer. Some of the managerial functions that will need to be addressed when developing a technology transfer strategy include the following:

1. Development of an innovation and technology transfer plan
2. Assessment of technological risk
3. Assignment/reassignment of personnel to implement the technology transfer
4. Establishment of a transfer manager and a technology transfer office; in many cases, transfer failures occur because no individual has been given the responsibility to ensure the success of technology transfer
5. Identification and allocation of the resources required for technology transfer
6. Setting of guidelines for technology transfer; for example,
   a. Specification of phases (Development, Testing, Transfer, etc.)
   b. Specification of requirements for interphase coordination
   c. Identification of training requirements
   d. Establishment and implementation of performance measurements
7. Identification of key factors (both qualitative and quantitative) associated with technology transfer and management
8. Investigation of how the factors interact and development of the hierarchy of importance for the factors
9. Formulation of a loop system model that considers the forward and backward chains of actions needed to effectively transfer and manage a given technology
10. Tracking of the outcome of the technology transfer

Technological developments in many industries appear in scattered, narrow, and isolated areas within a few selected fields. This makes it so technology efforts are rarely coordinated, thereby hampering the benefits of technology. The optimization of technology utilization is, thus, very difficult. To overcome this problem and establish the basis for effective technology transfer and management, an integrated approach must be followed. An integrated approach will be applicable to technology or innovation transfer between any two organizations, whether public or private.

Some nations concentrate on the acquisition of bigger, better, and faster technology. But little attention is given to how to manage and coordinate the operations of the technology once it arrives. When technology fails, it is not necessarily because the technology is deficient. Rather, it is often the communication, cooperation, and coordination functions of technology management that are deficient. Technology encompasses factors and attributes beyond mere hardware, software, and peopleware, which refers to people issues affecting the utilization of technology. This may involve social-economic and cultural issues of using certain technologies or innovative techniques. Consequently, innovation transfer involves more than the physical transfer of hardware and software. Several flaws exist in the common practices of technology transfer and management. These flaws include the following:

- *Poor fit*: This relates to an inadequate assessment of the needs of the organization receiving the technology. The target of the transfer may not have the capability to properly absorb the technology.
- *Premature transfer of technology*: This is particularly acute for emerging technologies that are prone to frequent developmental changes.
- *Lack of focus*: In the attempt to get a bigger share of the market or gain an early lead in the technological race, organizations frequently force technology in many incompatible directions.
- *Intractable implementation problems*: Once a new technology is in place, it may be difficult to locate sources of problems that have their roots in the technology transfer phase itself.
- *Lack of transfer precedents*: Very few precedents are available related to the management of brand new technology. Managers are, thus, often unprepared for their new technology management responsibilities.
- *Stuck on technology*: Unworkable technologies sometimes continue to be recycled needlessly in the attempt to find the "right" usage.
- *Lack of foresight*: Due to the nonexistence of a technology transfer model, managers may not have a basis against which they can evaluate future expectations.
- *Insensitivity to external events*: Some external events that may affect the success of technology transfer include trade barriers, taxes, and political changes.
- *Improper allocation of resources*: There are usually not enough resources available to allocate to technology alternatives. Thus, a technology transfer priority must be developed.

The following steps provide specific guidelines for pursuing the implementation of manufacturing technology transfer:

1. Find a suitable application
2. Commit to an appropriate technology
3. Perform economic justification

4. Secure management support for the chosen technology
5. Design the technology implementation to be compatible with existing operations
6. Formulate the project management approach to be used
7. Prepare the receiving organization for the technology change
8. Install the technology
9. Maintain the technology
10. Periodically review the performance of the technology based on prevailing goals

Innovation transfer modes

The transfer of technology can be achieved in various forms. Project management provides an effective means of ensuring proper transfer of technology. Three technology transfer modes are presented here to illustrate basic strategies for getting one technological product from one point (technology source) to another point (technology sink). A conceptual integrated model of the interaction between the technology source and sink is presented in Figure 1.3.

Innovation and technology application centers may be established to serve as a unified point for linking technology sources with interested targets. The center will facilitate interactions between business establishments, academic institutions, and government agencies to identify important technology needs. With reference to Figure 1.3, technology can be transferred in one or a combination of the following strategies:

1. Transfer of complete technological products: In this case, a fully developed product is transferred from a source to a target. Very little product development effort is carried out at the receiving point. However, information about the operations of the product is fed back to the source so that necessary product enhancements can be pursued. So, the technology recipient generates product information which facilitates further improvement at the technology source. This is the easiest mode of technology transfer and the most tempting. Developing nations are particularly prone to this type of transfer. Care must be exercised to ensure that this type of technology transfer does

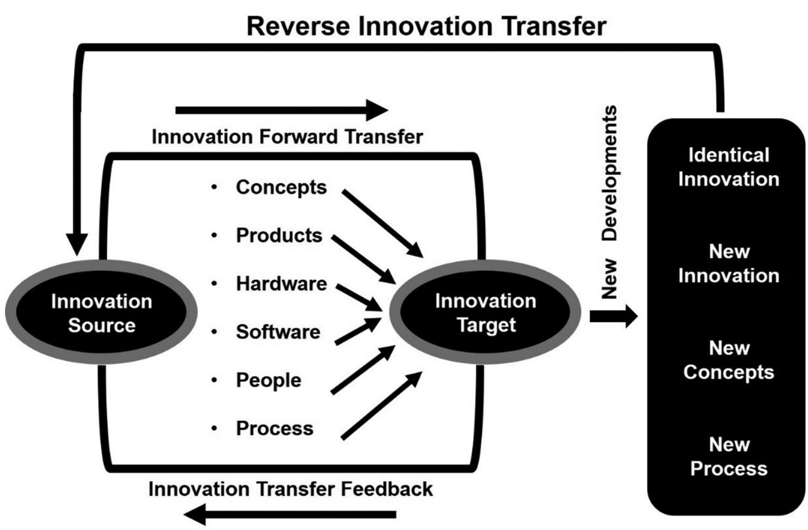

Figure 1.3 Technology transfer modes.

not degenerate into "machine transfer." It should be recognized that machines alone do not constitute technology.

2. Transfer of technology procedures and guidelines: In this technology transfer mode, procedures (e.g., blueprints) and guidelines are transferred from a source to a target. The technology blueprints are implemented locally to generate the desired services and products. The use of local raw materials and manpower is encouraged for the local production. Under this mode, the implementation of the transferred technology procedures can generate new operating procedures that can be fed back to enhance the original technology. With this symbiotic arrangement, a loop system is created whereby both the transferring and the receiving organizations derive useful benefits.
3. Transfer of technology concepts, theories, and ideas: This strategy involves the transfer of the basic concepts, theories, and ideas behind a given technology. The transferred elements can then be enhanced, modified, or customized within local constraints to generate new technological products. The local modifications and enhancements have the potential to generate an identical technology, a new related technology, or a new set of technology concepts, theories, and ideas. These derived products may then be transferred back to the original technology source as new technological enhancements. Figure 1.4 presents a specific cycle for local adaptation and modification of technology. An academic institution is a good potential source for the transfer of technology concepts, theories, and ideas.

It is very important to determine the mode in which technology will be transferred for defense purposes. There must be a concerted effort by people to make the transferred technology work within local infrastructure and constraints. Local innovation, patriotism, dedication, and willingness to adapt technology will be required to make technology transfer successful. It will be difficult for a nation to achieve national defense through total dependence on transplanted technology. Local adaptation will always be necessary.

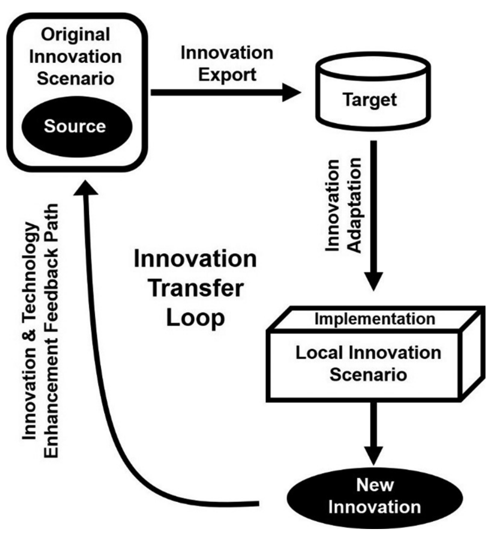

Figure 1.4 Local adaptation and enhancement of technology.

Innovation change-over strategies

One good innovation begets another. Thus, change-over arrangements are essential for a smooth transition between stages of innovation. Any development project will require changing from one form of technology to another. The implementation of a new technology to replace an existing (or a nonexistent) technology can be approached through one of several options. Some options are more suitable than others for certain types of technologies. The most commonly used technology change-over strategies include the following:

Parallel change-over: In this case, the existing technology and the new technology operate concurrently until there is confidence that the new technology is satisfactory.

Direct change-over: In this approach, the old technology is removed totally and the new technology takes over. This method is recommended only when there is no existing technology or when both technologies cannot be kept operational due to incompatibility or cost considerations.

Phased change-over: In this incremental change-over method, modules of the new technology are gradually introduced one at a time using either direct or parallel change-over.

Pilot change-over: In this case, the new technology is fully implemented on a pilot basis in a selected department within the organization.

Post-implementation evaluation

The new technology should be evaluated only after it has reached a steady-state performance level. This helps to avoid the bias that may be present at the transient stage due to personnel anxiety, lack of experience, or resistance to change. The system should be evaluated for the following aspects:

- Sensitivity to data errors
- Quality and productivity
- Utilization level
- Response time
- Effectiveness

Innovation systems integration

With the increasing shortages of resources, more emphasis should be placed on the sharing of resources. Technology resource sharing can involve physical equipment, facilities, technical information, ideas, and related items. The integration of technologies facilitates the sharing of resources. Technology integration is a major effort in technology adoption and implementation. Technology integration is required for proper product coordination. Integration facilitates the coordination of diverse technical and managerial efforts to enhance organizational functions, reduce cost, improve productivity, and increase the utilization of resources. Technology integration ensures that all performance goals are satisfied with a minimal expenditure of time and resources. It may require the adjustment of functions to permit sharing of resources, development of new policies to accommodate product integration, or realignment of managerial responsibilities. It can affect both hardware and software components of an organization. Important factors in technology integration include the following:

- Unique characteristics of each component in the integrated technologies
- Relative priorities of each component in the integrated technologies
- How the components complement one another
- Physical and data interfaces between the components
- Internal and external factors that may influence the integrated technologies
- How the performance of the integrated system will be measured

Role of government in innovation transfer

The malignant policies and operating characteristics of some of the governments in underdeveloped countries have contributed to stunted growth of technology in those parts of the world. The governments in most developing countries control the industrial and public sectors of the economy. People either work for the government or serve as agents or contractors for the government. The few industrial firms that are privately owned depend on government contracts to survive. Consequently, the nature of the government can directly determine the nature of industrial technological progress.

The operating characteristics of most of the governments perpetuate inefficiency, corruption, and bureaucratic bungles. This has led to a decline in labor and capital productivity in the industrial sectors. Using the Pareto distribution, it can be estimated that in most government-operated companies, there are eight administrative workers for every two production workers. This creates a non-productive environment that is skewed towards hyper-bureaucracy. The government of a nation pursuing industrial development must formulate and maintain an economic stabilization policy. The objective should be to minimize the sacrifice of economic growth in the short run and while maximizing long-term economic growth. To support industrial technology transfer efforts, it is essential that a conducive national policy be developed.

More emphasis should be placed on industry diversification, training of the work force, supporting financial structure for emerging firms, and implementing policies that encourage productivity in a competitive economic environment. Appropriate foreign exchange allocation, tax exemptions, bank loans for emerging businesses, and government-guaranteed low-interest loans for potential industrial entrepreneurs are some of the favorable policies to spur growth and development of the industrial sector.

Improper trade and domestic policies have adversely affected industrialization in many countries. Excessive regulations that cause bottlenecks in industrial enterprises are not uncommon. The regulations can take the form of licensing, safety requirements, manufacturing value-added quota requirements, capital contribution by multinational firms, and high domestic production protection. Although regulations are needed for industrial operations, excessive controls lead to low returns from the industrial sectors. For example, stringent regulations on foreign exchange allocation and control have led to the closure of industrial plants in some countries. The firms that cannot acquire essential raw materials, commodities, tools, equipment, and new technology from abroad due to foreign exchange restrictions are forced to close and lay off workers.

Price controls for commodities are used very often by developing countries especially when inflation rates for essential items are high. The disadvantages involved in price control of industrial goods include restrictions of the free competitive power of available goods in relation to demand and supply, encouragement of inefficiency, promotion of dual markets, distortion of cost relationships, and increases in administrative costs involved in producing goods and services.

NASA examples of innovation and technology transfer

One way that a government can help facilitate industrial technology transfer involves the establishment of technology transfer centers within appropriate government agencies. A good example of this approach can be seen in the government-sponsored technology transfer program by the US National Aeronautics and Space Administration (NASA). In the Space Act of 1958, the US Congress charged NASA with a responsibility to provide for the widest practical and appropriate dissemination of information concerning its activities and the results achieved from those activities. With this technology transfer responsibility, technology developed in the United States' space program is available for use by the nation's business and industry sector.

In order to accomplish technology transfer to industry, NASA established the Technology Utilization Program (TUP) in 1962. The Technology Utilization Program uses several avenues to disseminate information on NASA technology. The avenues include the following:

- Complete, clear, and practical documentation is required for new technology developed by NASA and its contractors. This is available to industry through several publications produced by NASA. An example is the monthly *Tech Briefs*, which outlines technology innovations. This is a source of prompt technology information for industry.
- Industrial Application Centers (IAC) were developed to serve as repositories for vast computerized data on technical knowledge. The IACs are located at academic institutions around the country. All the centers have access to a large data base containing millions of NASA documents. With this data base, industry can have access to the latest technological information quickly. The funding for the centers is obtained through joint contributions from several sources including NASA, the sponsoring institutions, and state government subsidies. Thus, the centers can provide their services at very reasonable rates.
- NASA operates a Computer Software Management and Information Center (COSMIC) to disseminate computer programs developed through NASA projects. COSMIC, which is located at a university, has a library of thousands of computer programs. The center publishes an annual index of available software.

In addition to the specific mechanisms discussed earlier, NASA undertakes Application Engineering Projects. Through these projects, NASA collaborates with industry to modify aerospace technology for use in industrial applications. To manage the application projects, NASA established a Technology Application Team (TAT), consisting of scientists and engineers from several disciplines. The team interacts with NASA field centers, industry, universities, and government agencies. The major mission of the team interactions is to define important technology needs and identify possible solutions within NASA. NASA Application Engineering Projects are usually developed in a five-phase approach with go or no-go decisions made by NASA and industry at the completion of each phase. The five phases are outlined in the following:

1. NASA and the Technology Applications Team meet with industry associations, manufacturers, university researchers, and public-sector agencies to identify important technology problems that might be solved by aerospace technology.

2. After a problem is selected, it is documented and distributed to the Technology Utilization Officer at each of NASA's field centers. The officer in turn distributes the description of the problem to the appropriate scientists and engineers at the center. Potential solutions are forwarded to the team for review. The solutions are then screened by the problem originator to assess the chances for technical and commercial success.
3. Next is the development of partnerships and a project plan to pursue the implementation of the proposed solution. NASA joins forces with private companies and other organizations to develop an Application Engineering Project. Industry participation is encouraged through a variety of mechanisms such as simple letters of agreement or joint endeavor contracts. The financial and technical responsibilities of each organization are specified and agreed upon.
4. At this point, NASA's primary role is to provide technical assistance to facilitate utilization of the technology. The costs for these projects are usually shared by NASA and the participating companies. The proprietary information provided by the companies and their rights to new discoveries are protected by NASA.
5. The final phase involves the commercialization of the product. With the success of commercialization, the project would have widespread impact. Usually, the final product development, field testing, and marketing are managed by private companies without further involvement from NASA.

Through this well-coordinated government-sponsored technology transfer program, NASA has made significant contributions to US industry, thereby providing an anchor for national defense pursuits. The results of NASA's technology transfer abound in numerous consumer products either in subtle forms or in clearly identifiable forms. Food preservation techniques constitute one area of NASA's technology transfer that has had a significant positive impact on the society. Although the specific organization and operation of the NASA technology transfer programs have changed in name or in deed over the years, the basic descriptions outlined earlier remain a viable template for how to facilitate manufacturing technology transfer. In a similar government-backed strategy, the US Air Force Research Laboratory (AFRL) also has very structured programs for transferring non-classified technology to the industrial sector. It is believed that a project management approach can help in facilitating success with innovation and technology transfer efforts.

PICK'ing the right innovation

It is important to pick the right innovation to adopt and adapt. The question of which innovation is appropriate to transfer in or transfer out is relevant for technology transfer considerations. While several methods of technology selection are available, this book recommends methods that combine qualitative and quantitative factors. The Analytic Hierarchy Process (AHP) is one such method. Another useful, but less publicized, is the PICK chart. The PICK chart was originally developed by Lockheed Martin to identify and prioritize improvement opportunities in the company's process improvement applications. The technique is just one of the several decision tools available in process improvement endeavors. It is a very effective technology selection tool used to categorize ideas and opportunities. The purpose is to qualitatively help identify the most useful ideas. A 2×2 grid is normally drawn on a white board or large flip-chart. Ideas that were written on sticky notes by team members are placed on the grid based on a group assessment of the payoff relative the level of difficulty. The PICK acronym comes from the labels for each of the quadrants of the grid: **P**ossible (easy, low payoff), **I**mplement (easy, high payoff), **C**hallenge (hard, high payoff), and **K**ill (hard, low payoff). The PICK chart quadrants are summarized as follows:

Possible (easy, low payoff)	→ Third quadrant
Implement (easy, high payoff)	→ Second quadrant
Challenge (hard, high payoff)	→ First quadrant
Kill (hard, low payoff).	→ Fourth quadrant

The primary purpose is to help identify the most useful ideas, especially those that can be accomplished immediately with little difficulty. These are called "Just-Do-Its." The general layout of the PICK chart grid is shown in Figure 1.5. The PICK process is normally done subjectively by a team of decision makers under a group decision process. This can lead to bias and protracted debate of where each item belongs. It is desired to improve the efficacy of the process by introducing some quantitative analysis. Badiru and Thomas (2013) present a methodology to achieve a quantification of the PICK selection process. The PICK chart is often criticized for its subjective rankings and lack of quantitative analysis. The approach presented by Badiru and Thomas (2013) alleviates such concerns by normalizing and quantifying the process of integrating the subjective rakings by those involved in the group PICK process. Human decision is inherently subjective. All we can do is to develop techniques to mollify the subjective inputs rather than compounding them with subjective summarization.

PICK chart quantification methodology

The placement of items into one of the four categories in a PICK chart is done through expert ratings, which are often subjective and non-quantitative. In order to put some quantitative basis to the PICK chart analysis, Badiru and Thomas (2013) present the methodology

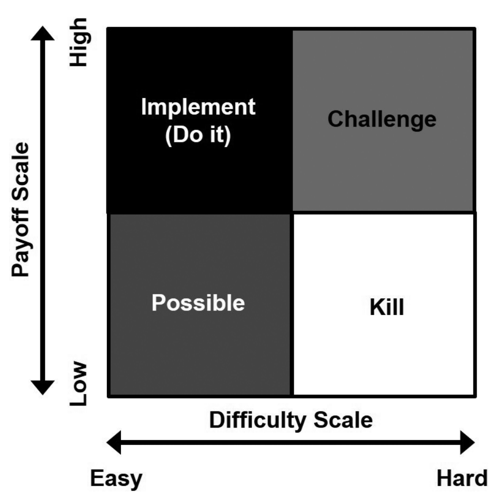

Figure 1.5 Basic layout of the PICK chart.

of dual numeric scaling on the impact and difficulty axes. Suppose each technology is ranked on a scale of one to ten and plotted accordingly on the PICK chart. Then, each project can be evaluated on a binomial pairing of the respective rating on each scale. Note that a high rating along the x axes is desirable while a high rating along the y axis is not desirable. Thus, a composite rating involving x and y must account for the adverse effect of high values of y. A simple approach is to define $y' = (11-y)$, which is then used in the composite evaluation. If there are more factors involved in the overall project selection scenario, the other factors can take on their own lettered labeling (e.g., a, b, c, z, etc.). Then, each project will have an n-factor assessment vector. In its simplest form, this approach will generate a rating such as the following:

$$PICK_{R,i}(x, y') = x + y'$$

where:

$PICK_{R,i}(x, y')$ is the PICK rating of project i ($i = 1, 2, 3, \ldots, n$)
x is the rating along the impact axis ($1 \leq x \leq 10$)
y is the rating along the difficulty axis ($1 \leq y \leq 10$)
y' is the $(11-y)$

If $x + y'$ is the evaluative basis, then each technology's composite rating will range from 2 to 20, 2 being the minimum and 20 being the maximum possible. If $(x)(y)$ is the evaluative basis, then each project's composite rating will range from 1 to 100. In general, any desired functional form may be adopted for the composite evaluation. Another possible functional form is:

$$\begin{aligned} PICK_{R,i}(x, y'') &= f(x, y'') \\ &= (x + y'')^2, \end{aligned}$$

where y'' is defined as needed to account for the converse impact of the axes of difficulty. The previous methodology provides a quantitative measure for translating the entries in a conventional PICK chart into an analytical technique to rank the technology alternatives, thereby reducing the level of subjectivity in the final decision. The methodology can be extended to cover cases where a technology has the potential to create negative impacts, which may impede organizational advancement.

The quantification approach facilitates a more rigorous analytical technique compared to traditional subjective approaches. One concern is that although quantifying the placement of alternatives on the PICK chart may improve the granularity of relative locations on the chart, it still does not eliminate the subjectivity of how the alternatives are assigned to quadrants in the first place. This is a recognized feature of many decision tools. This can be mitigated by the use of additional techniques that aid decision makers to refine their choices. The analytic hierarchy process (AHP) could be useful for this purpose. Quantifying subjectivity is a continuing challenge in decision analysis. The PICK chart quantification methodology offers an improvement over the conventional approach.

Although the PICK chart has been used extensively in industry, there are few published examples in the open literature. The quantification approach presented by Badiru and Thomas (2013) may expand interest and applications of the PICK chart among technology researchers and practitioners. The steps for implementing a PICK chart are summarized in the following:

Step 1: On a chart, place the subject question. The question needs to be asked and answered by the team at different stages to be sure that the data that is collected is relevant.
Step 2: Put each component of the data on a different note like a post-it or small cards. These notes should be arranged on the left side of the chart.
Step 3: Each team member must read all notes individually and consider the importance of each. The team member should decide whether the element should or should not remain a fraction of the significant sample. The notes are then removed and moved to the other side of the chart. Now, the data is condensed enough to be processed for a particular purpose by means of tools that allow groups to reach a consensus on priorities of subjective and qualitative data.
Step 4: Apply the quantification methodology presented earlier to normalize the qualitative inputs of the team.

DEJI model for innovation integration

In the Foreword of this handbook, Joe Sciabica suggested taking any innovation pursuit through of the ***Heilmeier Catechism***, which helps separate the wheat from the chaff when assessing the value of new innovation. How do we know if a concept or idea is technologically sound, adds value, and is truly "innovative"? The stages of ***Heilmeier Catechism*** are:

1. In the most simplistic terms what are you trying to do and why?
2. How is it done today and what are the limits of current practice?
3. What is new in your approach and why do you think it will be successful? Who cares?
4. If you are successful, what difference will it make?
5. What are the risks?
6. How much will it cost?
7. How long will it take?
8. What are the mid-term and final "exams" to check for success?

It is believed that the stages espoused by the DEJI model of systems engineering align well with fulfilling the requirements of the catechism with respect to design, evaluation, justification, and integration. It is the requirement for explicit integration that makes the DEJI model effective and applicable to all spheres of human endeavor. If a new product or process cannot be sustainably integrated into normal practice and prevailing pattern of operation, the new innovation would be out of alignment and would not add value.

Technology is at the intersection of efficiency, effectiveness, and productivity. Efficiency provides the framework for quality in terms of resources and inputs required to achieve the desired level of quality. Effectiveness comes into play with respect to the application of product quality to meet specific needs and requirements of an organization. Productivity is an essential factor in the pursuit of quality as it relates to the throughput of a production system. To achieve the desired levels of quality, efficiency, effectiveness, and productivity, a new technology integration framework must be adopted. This section presents a technology integration model for design, evaluation, justification, and integration (DEJI) based on the product development application presented by Badiru (2012). The model is relevant for

Table 1.2 DEJI model for technology integration

DEJI model	Characteristics	Tools & techniques
Design	Define goals	Parametric assessment
	Set performance metrics	Project state transition
	Identify milestones	Value stream analysis
Evaluate	Measure parameters	Pareto distribution
	Assess attributes	Life cycle analysis
	Benchmark results	Risk assessment
Justify	Assess economics	Benefit-cost ratio
	Assess technical output	Payback period
	Align with goals	Present value
Integrate	Embed in normal operation	SMART concept
	Verify symbiosis	Process improvement
	Leverage synergy	Quality control

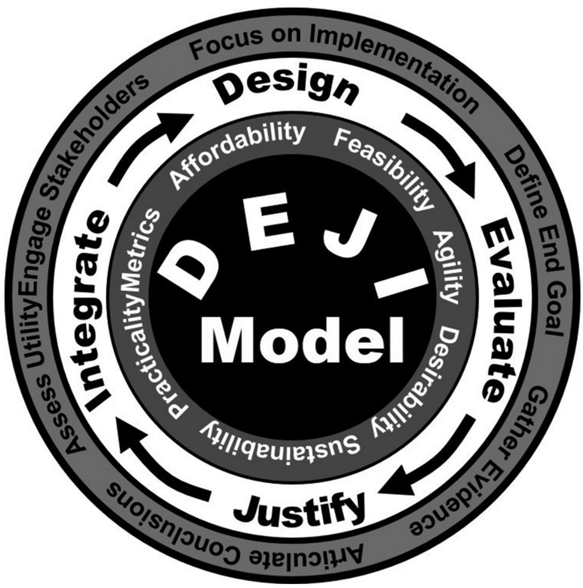

Figure 1.6 DEJI systems model for innovation integration.

research and development efforts in industrial development and technology applications. The DEJI model encourages the practice of building quality into a product right from the beginning so that the product or technology integration stage can be more successful. The essence of the model is summarized in Table 1.2. Figure 1.6 shows the graphical framework for the model.

Design for innovation implementation

The design of quality in product development should be structured to follow point-to-point transformations. A good technique to accomplish this is the use of state-space transformation, with which we can track the evolution of a product from the concept stage to a final product stage. For the purpose of product quality design, the following definitions are applicable:

Product state: A state is a set of conditions that describe the product at a specified point in time. The *state* of a product refers to a performance characteristic of the product which relates input to output such that a knowledge of the input function over time and the state of the product at time $t = t_0$ determines the expected output for $t \geq t_0$. This is particularly important for assessing where the product stands in the context of new technological developments and the prevailing operating environment.

Product state space: A product *state-space* is the set of all possible states of the product lifecycle. State-space representation can solve product design problems by moving from an initial state to another state, and eventually to the desired end-goal state. The movement from state to state is achieved by means of actions. A goal is a description of an intended state that has not yet been achieved. The process of solving a product problem involves finding a sequence of actions that represents a solution path from the initial state to the goal state. A state-space model consists of state variables that describe the prevailing condition of the product. The state variables are related to inputs by mathematical relationships. Examples of potential product state variables include schedule, output quality, cost, due date, resource, resource utilization, operational efficiency, productivity throughput, and technology alignment. For a product described by a system of components, the state-space representation can follow the quantitative metric in the following:

$$Z = f(z, x); \; Y = g(z, x)$$

where f and g are vector-valued functions. The variable Y is the output vector while the variable x denotes the inputs. The state vector Z is an intermediate vector relating x to y. In generic terms, a product is transformed from one state to another by a driving function that produces a transitional relationship given by:

$$S_s = f(x \mid S_p) + e,$$

where:

S_s = subsequent state
x = state variable
S_p = the preceding state
e = error component

The function f is composed of a given action (or a set of actions) applied to the product. Each intermediate state may represent a significant milestone in the project. Thus, a descriptive state-space model facilitates an analysis of what actions to apply in order to achieve the next desired product state. The state-space representation can be expanded to cover several components within the technology integration framework. Hierarchical linking of product elements provides an expanded transformation structure. The product state can be expanded in accordance with implicit requirements. These requirements might include grouping design elements, linking precedence requirements (both technical and procedural), adapting to new technology developments, following required communication links, and accomplishing reporting requirements. The actions to be taken at each state depend on the prevailing product conditions. The nature of subsequent alternate states depends on what actions are implemented. Sometimes there are multiple paths that can lead to the desired end result. At other times, there exists only one unique path to the desired objective. In conventional practice, the characteristics of the future states can only be recognized after the fact, thus making it impossible to develop adaptive plans. In the implementation of the **DEJI** model, adaptive plans can be achieved because the events occurring within and outside the product state boundaries can be taken into account. If we describe a product by P state variables s_i, then the composite state of the product at any given time can be represented by a vector $\boldsymbol{S}$ containing P elements. That is,

$$\boldsymbol{S} = \left\{s_1, s_2, \ldots, s_P\right\}$$

The components of the state vector could represent either quantitative or qualitative variables (e.g., cost, energy, color, time). We can visualize every state vector as a point in the state-space of the product. The representation is unique since every state vector corresponds to one and only one point in the state-space. Suppose we have a set of actions (transformation agents) that we can apply to the product information so as to change it from one state to another within the project state-space. The transformation will change a state vector into another state vector. A transformation may be a change in raw material or a change in design approach. The number of transformations available for a product characteristic may be finite or unlimited. We can construct trajectories that describe the potential states of a product evolution as we apply successive transformations with respect to technology forecasts. Each transformation may be repeated as many times as needed. Given an initial state $\boldsymbol{S}_0$, the sequence of state vectors is represented by the following:

$$\boldsymbol{S}_n = T_n(\boldsymbol{S}_{n-1})$$

The state-by-state transformations are then represented as $\boldsymbol{S}_1 = T_1(\boldsymbol{S}_0)$; $\boldsymbol{S}_2 = T_2(\boldsymbol{S}_1)$; $\boldsymbol{S}_3 = T_3(\boldsymbol{S}_2)$; …; $\boldsymbol{S}_n = T_n(\boldsymbol{S}_{n-1})$. The final State, $\boldsymbol{S}_n$, depends on the initial state $\boldsymbol{S}$ and the effects of the actions applied.

Evaluation of innovation

A product can be evaluated on the basis of cost, quality, schedule, and meeting requirements. There are many quantitative metrics that can be used in evaluating a product at this stage. Learning curve productivity is one relevant technique that can be used because it offers an evaluation basis of a product with respect to the concept of growth and decay. The half-life extension (Badiru, 2012) of the basic learning is directly applicable because the half-life of the technologies going into a product can be considered. In today's technology-based operations, retention of learning may be threatened by fast-paced shifts in operating requirements. Thus, it is of interest to evaluate the half-life properties of new technologies as they impact the overall product quality. Information about the half-life can tell us something about the sustainability of learning-induced technology performance. This is particularly useful for designing products whose life cycles stretch into the future in a high-tech environment.

Justification of innovation tool

We need to justify a program on the basis of quantitative value assessment. The Systems Value Model (SVM) is a good quantitative technique that can be used here for project justification on the basis of value. The model provides a heuristic decision aid for comparing project alternatives. It is presented here again for the present context. Value is represented as a deterministic vector function that indicates the value of tangible and intangible attributes that characterize the project. It is represented as $V = f(A_1, A_2, ..., A_p)$, where V is the assessed value and the A values are quantitative measures or attributes. Examples of product attributes are quality, throughput, manufacturability, capability, modularity, reliability, interchangeability, efficiency, and cost performance. Attributes are considered to be a combined function of factors. Examples of product factors are market share, flexibility, user acceptance, capacity utilization, safety, and design functionality. Factors are themselves considered to be composed of indicators. Examples of indicators are debt ratio, acquisition volume, product responsiveness, substitutability, lead time, learning curve, and scrap volume. By combining the earlier definitions, a composite measure of the operational value of a product can be quantitatively assessed. In addition to the quantifiable factors, attributes, and indicators that impinge upon overall project value, the human-based subtle factors should also be included in assessing overall project value.

Integration of innovation

Without being integrated, a system will be in isolation and it may be worthless. We must integrate all the elements of a system on the basis of alignment of functional goals. The overlap of systems for integration purposes can conceptually be viewed as projection integrals by considering areas bounded by the common elements of subsystems. Quantitative metrics can be applied at this stage for effective assessment of the technology state. Trade-off analysis is essential in technology integration. Pertinent questions include the following:

What level of trade-offs on the level of technology are tolerable?
What is the incremental cost of more technology?
What is the marginal value of more technology?
What is the adverse impact of a decrease in technology utilization?

What is the integration of technology over time? In this respect, an integral of the form in the following may be suitable for further research:

$$I = \int_{t_1}^{t_2} f(q)dq$$

where:

I is the integrated value of quality
$f(q)$ is the functional definition of quality
t_1 is the initial time
t_2 is the final time within the planning horizon.

Guidelines and important questions relevant for technology integration are presented in the following:

- What are the unique characteristics of each component in the integrated system?
- How do the characteristics complement one another?
- What physical interfaces exist among the components?
- What data/information interfaces exist among the components?
- What ideological differences exist among the components?
- What are the data flow requirements for the components?
- What internal and external factors are expected to influence the integrated system?
- What are the relative priorities assigned to each component of the integrated system?
- What are the strengths and weaknesses of the integrated system?
- What resources are needed to keep the integrated system operating satisfactorily?
- Which organizational unit has primary responsibility for the integrated system?

The recommended approach of the DEJI model will facilitate a better alignment of product technology with future development and needs. The stages of the model require research for each new product with respect to design, evaluation, justification, and integration. Existing analytical tools and techniques can be used at each stage of the model.

Conclusion

Technology transfer is a great avenue to advancing industrialization. This chapter has presented a variety of principles, tools, techniques, and strategies useful for managing technology transfer. Of particular emphasis in the chapter are the management aspects of technology transfer. The technical characteristics of the technology of interest are often well understood. What is often lacking is an appreciation of the technology management requirements for achieving a successful technology transfer. This chapter presents the management aspects of manufacturing technology transfer.

References

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chapter two

Definitional analysis of innovation[*]

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Contents

Introduction

A definitional analysis of innovation is essential for getting the intended full benefit of this chapter. Joe Sciabica, in the FOREWORD, reminded us of a dictionary definition of innovation:

> "Innovation a (noun) + a (verb) - The portfolio of financial, intellectual, organization and human capabilities that enable a society's journey to its desired future."

This definition of innovation conveys the multifaceted operational meaning of the word. This may help readers to put everything into the proper perspective. Innovation is widely heralded as essential for successful competition in the increasingly global economy. However, to enhance innovation in education, organizations and countries require transformative thinking. National thought leaders and organizations such as the National Academy of Engineering are supporting projects to explore this relationship. The Educate to Innovate (ETI) project was designed to explore the issue regarding teaching innovation and the expected outcome, entrepreneurship [1].

[*] This chapter is adapted and modified with copyright permission from Chapter 2 (The role of Creativity and Innovation in Leadership) of McCauley, Pamela (2017), **Essentials of Engineering Leadership and Innovation**, CRC Press/Taylor & Francis, Boca Raton, Florida.