Innovation, Technology, and Knowledge Management

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R&D Management in the Knowledge Era

Challenges of Emerging Technologies

Springer

Innovation, Technology, and Knowledge Management

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Series Foreword

The Springer book series *Innovation, Technology, and Knowledge Management* was launched in March 2008 as a forum and intellectual, scholarly "podium" for global/local, transdisciplinary, transsectoral, public–private, and leading/"bleeding"-edge ideas, theories, and perspectives on these topics.

The book series is accompanied by the Springer *Journal of the Knowledge Economy*, which was launched in 2009 with the same editorial leadership.

The series showcases provocative views that diverge from the current "conventional wisdom," that are properly grounded in theory and practice, and that consider the concepts of *robust competitiveness*,[1] *sustainable entrepreneurship*,[2] and *democratic capitalism*[3] central to its philosophy and objectives. More specifically, the aim of this series is to highlight emerging research and practice at the dynamic intersection of these fields, where individuals, organizations, industries, regions, and nations are harnessing creativity and invention to achieve and sustain growth.

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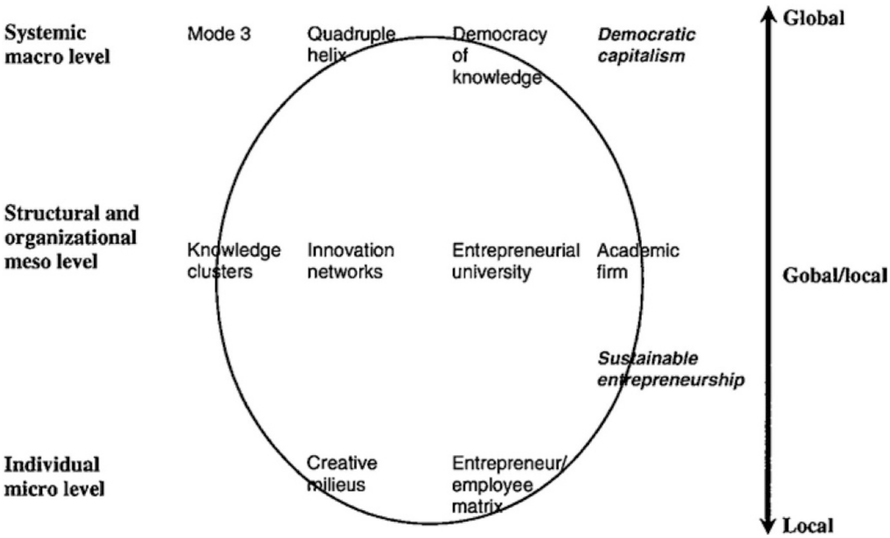
[1]We define *sustainable entrepreneurship* as the creation of viable, profitable, and scalable firms. Such firms engender the formation of self-replicating and mutually enhancing innovation networks and knowledge clusters (innovation ecosystems), leading toward robust competitiveness (E.G. Carayannis, *International Journal of Innovation and Regional Development* 1(3), 235–254, 2009).

[2]We understand *robust competitiveness* to be a state of economic being and becoming that avails systematic and defensible "unfair advantages" to the entities that are part of the economy. Such competitiveness is built on mutually complementary and reinforcing low-, medium-, and hightechnology and public and private sector entities (government agencies, private firms, universities, and nongovernmental organizations) (E.G. Carayannis, *International Journal of Innovation and Regional Development* 1(3), 235–254, 2009).

[3]The concepts of *robust competitiveness* and *sustainable entrepreneurship* are pillars of a regime that we call *democratic capitalism* (as opposed to "popular or casino capitalism"), in which real opportunities for education and economic prosperity are available to all, especially—but not only—younger people. These are the direct derivative of a collection of top-down policies as well as bottom-up initiatives (including strong research and development policies and funding, but going beyond these to include the development of innovation networks and knowledge clusters across regions and sectors) (E.G. Carayannis and A. Kaloudis, *Japan Economic Currents,* pp. 6–10, January 2009).

Books that are part of the series explore the impact of innovation at the "macro" (economies, markets), "meso" (industries, firms), and "micro" levels (teams, individuals), drawing from such related disciplines as finance, organizational psychology, research and development, science policy, information systems, and strategy, with the underlying theme that for innovation to be useful, it must involve the sharing and application of knowledge.

Some of the key anchoring concepts of the series are outlined in the figure below and the definitions that follow (all definitions are from Carayannis and Campbell (2009)).



Conceptual profile of the series *Innovation, Technology, and Knowledge Management*:

- The "Mode 3" Systems Approach for Knowledge Creation, Diffusion, and Use: "Mode 3" is a multilateral, multinodal, multimodal, and multilevel systems approach to the conceptualization, design, and management of real and virtual, "knowledge-stock" and "knowledge-flow," modalities that catalyze, accelerate, and support the creation, diffusion, sharing, absorption, and use of cospecialized knowledge assets. "Mode 3" is based on a system-theoretic perspective of socioeconomic, political, technological, and cultural trends and conditions that shape the coevolution of knowledge with the "knowledge-based and knowledge-driven, global/local economy and society."
- Quadruple Helix: Quadruple helix, in this context, means to add to the triple helix of government, university, and industry a "fourth helix" that we identify as the "media-based and culture-based public." This fourth helix associates with "media," "creative industries," "culture," "values," "lifestyles," "art," and perhaps also the notion of the "creative class."

- Innovation Networks: Innovation networks are real and virtual infrastructures and infratechnologies that serve to nurture creativity, trigger invention, and catalyze innovation in a public and/or private domain context (for instance, government–university–industry public–private research and technology development coopetitive partnerships).
- Knowledge Clusters: Knowledge clusters are agglomerations of cospecialized, mutually complementary, and reinforcing knowledge assets in the form of "knowledge stocks" and "knowledge flows" that exhibit self-organizing, learning-driven, dynamically adaptive competences and trends in the context of an open systems perspective.
- Twenty-First-Century Innovation Ecosystem: A twenty-first-century innovation ecosystem is a multilevel, multimodal, multinodal, and multiagent system of systems. The constituent systems consist of innovation metanetworks (networks of innovation networks and knowledge clusters) and knowledge metaclusters (clusters of innovation networks and knowledge clusters) as building blocks and organized in a self-referential or chaotic fractal knowledge and innovation architecture (Carayannis 2001), which in turn constitute agglomerations of human, social, intellectual, and financial capital stocks and flows as well as cultural and technological artifacts and modalities, continually coevolving, cospecializing, and cooperating. These innovation networks and knowledge clusters also form, reform, and dissolve within diverse institutional, political, technological, and socioeconomic domains, including government, university, industry, and nongovernmental organizations and involving information and communication technologies, biotechnologies, advanced materials, nanotechnologies, and next-generation energy technologies.

Who is this book series published for? The book series addresses a diversity of audiences in different settings:

1. *Academic communities*: Academic communities worldwide represent a core group of readers. This follows from the theoretical/conceptual interest of the book series to influence academic discourses in the fields of knowledge, also carried by the claim of a certain saturation of academia with the current concepts and the postulate of a window of opportunity for new or at least additional concepts. Thus, it represents a key challenge for the series to exercise a certain impact on discourses in academia. In principle, all academic communities that are interested in knowledge (knowledge and innovation) could be tackled by the book series. The interdisciplinary (transdisciplinary) nature of the book series underscores that the scope of the book series is not limited a priori to a specific basket of disciplines. From a radical viewpoint, one could create the hypothesis that there is no discipline where knowledge is of no importance.
2. *Decision-makers—private/academic entrepreneurs and public (governmental, subgovernmental) actors*: Two different groups of decision-makers are being addressed simultaneously: (1) private entrepreneurs (firms, commercial firms, academic firms) and academic entrepreneurs (universities), interested in optimizing

knowledge management and in developing heterogeneously composed knowledge-based research networks, and (2) public (governmental, subgovernmental) actors that are interested in optimizing and further developing their policies and policy strategies that target knowledge and innovation. One purpose of public *knowledge and innovation policy* is to enhance the performance and competitiveness of advanced economies.

3. *Decision-makers in general*: Decision-makers are systematically being supplied with crucial information, for how to optimize knowledge-referring and knowledge-enhancing decision-making. The nature of this "crucial information" is conceptual as well as empirical (case study-based). Empirical information highlights practical examples and points toward practical solutions (perhaps remedies); conceptual information offers the advantage of further-driving and further-carrying tools of understanding. Different groups of addressed decisionmakers could be decision-makers in private firms and multinational corporations, responsible for the knowledge portfolio of companies; knowledge and knowledge management consultants; globalization experts, focusing on the internationalization of research and development, science and technology, and innovation; experts in university/business research networks; and political scientists, economists, and business professionals.
4. *Interested global readership*: Finally, the Springer book series addresses a whole global readership, composed of members who are generally interested in knowledge and innovation. The global readership could partially coincide with the communities as described above ("academic communities," "decision-makers"), but could also refer to other constituencies and groups.

Washington, DC, USA Elias G. Carayannis

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Carayannis, E. G., & Campbell, D. F. J. (2009). "Mode 3" and "Quadruple Helix": toward a 21st century fractal innovation ecosystem. *International Journal of Technology Management*, *46*(3–4), 201–234.

Preface

Technology and engineering is no longer a luxury afforded by a select few, but it is a requirement for all. Research and development (R&D) has always played a critical role in the engineering and technology focused industries. In an era of abundant and big data and smart applications, knowledge has become a key enabler for R&D. Managing R&D in the knowledge era requires use of key tools and methods. However, emerging technologies pose many challenges and cause uncertainties or discontinuities, which make the task of managing R&D even more difficult.

This edited volume explores emerging models, methods, and tools in the management of R&D in the knowledge era, with a particular focus on the challenges of the emerging technologies.

This book is prepared for educating the future leaders who will be responsible for managing technology and engineering in their organizations. It can be very well used as a textbook in a graduate class or can be used as a personal guide for those wishing to brush up their knowledge of technology and engineering management.

The book has five parts.

The first part is "Managing Emerging Technologies." There are five chapters in this part. This part demonstrates different tools and cases of managing technology and engineering through multiple emerging technologies.

The second part is "Technology and Engineering Management Tools." There are six chapters in this part. Each chapter provides a detailed application of an emerging methodology.

The third part is "Technology Innovation and Entrepreneurship." There are five chapters in this part. These chapters explore entrepreneurship and adoption of technological innovations.

The fourth part is "Commercialization of Technological Innovations." There are four chapters in this part. They explore different aspects of technology transfer.

The fifth and final part is “Managing the Engineering Enterprise.” This part has four chapters providing a review of basic tools used to manage engineering organizations.

We hope this volume will serve as a source of knowledge for future leaders in the technology and engineering world.

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Part I
Managing Emerging Technologies

Introduction

Managing engineering and technology is a challenging proposition. There are many aspects of it. One of the major reasons for the challenge is the nature of emerging technologies or the uncertainty they pose.

This part provides a framework developed through military experience. The case provides detailed insight into how technology was managed in the military.

Chapter 1 provides a review of technology management literature with a systemic bibliometric approach, providing very useful insight.

Chapter 2 provides a sustainability analysis for solar power, thus providing a framework for other power sources. Chapter 3 provides another example by focusing on meter energy storage.

Chapter 4 provides an assessment approach to explore the adoption of emerging technologies by focusing on the health care sector.

Chapter 5 provides a planning process to manage a portfolio of emerging technologies.

Chapter 1
Information Science and Technology: A New Paradigm in Military Medical Research

Karl E. Friedl, Thomas B. Talbot, and Steve Steffensen

Where is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?
T.S. Eliot, The Rock, 1934 [1]

1.1 Introduction

Beginning in FY2010, the Defense Health Program included funding for research and development, specifically in Health Information Technology and Informatics. It was expected that this funding would provide the opportunity to address capability gaps through focused research initiatives and reduce programmatic risks for health care enterprise information technology projects. This funded program was labelled the Medical Simulation Training and Information Science research program (Joint Programmatic Committee 1). This program was consistent with the artificial intelligence and net-centric technological focus of the rest of the military. It also recognized important technological advances affecting information processing and access such as smart phones and high-performance computing. As a medical research domain with no significant investment by any of the Armed Services, this presented an opportunity to create a new program free of legacy laboratories, stove-piped thinking, and traditional lanes in discovery science models. Advances in computing technology and in neurobiology enable this worldwide transformation from discovery science to information science. The transdisciplinary merge of engineering, mathematics, and physics with life scientists and their problem sets

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has been termed "convergence" and described as the third revolution in medicine, after the advances that followed molecular biology technologies and the human genome project.

The Telemedicine and Advanced Technology Research Center (TATRC) has been uniquely positioned in the DoD to provide a tri-service base for convergence science. Originally established by Colonel Fred Goeringer as the Medical Advanced Technology Management Office (MATMO) to develop technological solutions to health information problems, the organization worked with industry for the first large-scale deployment of a standardized Picture Archiving and Communication System (PACS) in DoD radiology clinics [2, 3] (Fig. 1.1). The Army PACS evolved into the Medical Digital Imaging System (MDIS) which spurred the adoption of the Digital Imaging and Communications in Medicine (DICOM) connectivity standards through a requirement in the MDIS procurement documents to use DICOM. For a decade, under the direction of Air Force Colonel Jeff Roller, TATRC expanded the concept of use-inspired research based on technology implementation experiments. In recent years, the TATRC research model was used as a convergence science approach, especially through cooperative partnerships with the Center for Integration of Medicine and Innovation Technology (CIMIT, Boston, Massachusetts) [4], the Center for Advanced Surgical and Interventional Technology (CASIT, UCLA, Los Angeles, California) [5, 6], the Imaging Science and Information Systems

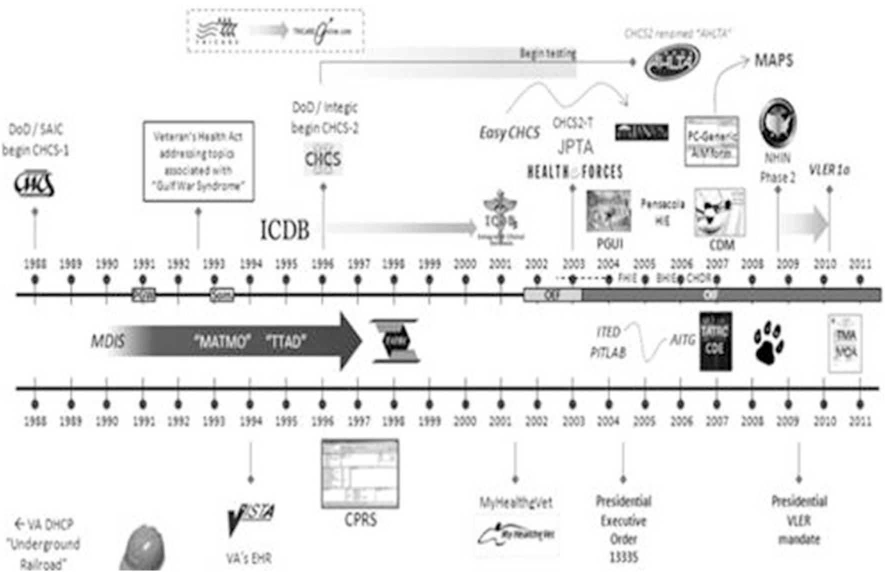

Fig. 1.1 Timeline of health information technology research and development in the DoD, highlighting major milestones and key external influences. TATRC was founded to address a need for a DoD information technology research integration center, beginning with the problem of digitizing radiological images

Center (ISIS, Georgetown University, Washington DC) [7], and other important extramural collaborators.

The research in this JPC1 program was broadly categorized by the following customer and problem focus areas: (a) medical simulation and training systems, (b) mobile health (m-Health), (c) open electronic health record and medical systems interoperability, (d) computational biology and predictive models, and (e) knowledge engineering. These categories are highly interrelated, offering solution sets with soft borders that are characteristic of convergence science. This paper outlines the military's research needs, implementation challenges, successes and initiatives, and planned program vision that established this program.

1.2 Research Drivers

The key requirements that were identified for this new area of research in the DoD came from a variety of sources (Table 1.1). Solving problems for military medicine benefits the nation and not just the military. These problems are more likely to be solved if the DoD champions and funds the research now, instead of waiting for an off-the-shelf solution created when someone else discovers a need and a market opportunity. The warfighter becomes an early beneficiary if the DoD is also an early adopter of the research findings. Cooperative agreement grants allow the DOD and

Table 1.1 Key drivers for JPC1 research

• Ensure that joint medical information systems are fully networked and interoperable among services to support integrated medical warning systems, health surveillance, timely health risk assessments, and timely use of appropriate health risk countermeasures (Joint Force Health Protection Concept of Operations, July 2007)
• Produce a "virtual lifetime electronic record" to support VA-DoD electronic health record data exchange (President Obama, April 2009; FY08 National Defense Authorization Act)
• Address patient safety for medical systems (National Coordination Office for Networking and Information Technology Research and Development, "High-Confidence Medical Devices: Cyber-Physical Systems for twenty-first Century Health Care," Feb 2009)
• Improve access to care through telebehavioral health options in CONUS and during deployment (Blue Ribbon Panel, General Amos and General Chiarelli, Uniformed Services University of the Health Sciences, 1 Sep 2009)
• Develop medical stability operations (MSOs) education and training programs that promote interoperability and information sharing between agencies, foreign governments, and NGOs (DoDI 6000.16, "Military Health Support for Stability Operations," 17 May 2010)
• Develop standardized training at the METC for medical enlisted specialties enhancing interoperability and joint deployability (Base Realignment and Closure Commission, 2005)
• Reduce live tissue use in medical training (Use of Live Animals in Medical Education and Training Joint Analysis Team report, 12 Jul 2009)
• Improve technology options to address TBI, PTSD, prosthetics, restoration of sight, and other battlefield injuries (Secretary Robert Gates, 26 Jun 2008)

extramural organizations to work collaboratively to solve these problems for the warfighters and the population in general.

1.3 Research Challenges

The JPC1 program concept has all the advantages of a new program unburdened by legacy research approaches and infrastructure, but it also faces some formidable challenges, with new approaches needed for research and research management (Table 1.2). Communications and computing technologies are advancing so rapidly that new research designs and evaluation processes must be identified to keep with the advances. The results of randomized controlled trials may be irrelevant by the time they are available because of the short half-life of the technologies evaluated (e.g., smart phone patient-provider interactions rapidly replacing video-teleconferencing center approaches). Standard approaches to peer review hypothesis-driven research may be inappropriate in convergence science efforts addressing a technology implementation and evaluation problem. The laboratory is not a conventional fixed facility wet lab; it is more likely a distributed network of scientists with common access to test environments and shared datasets. Projects require testing in limited microcosms such as regional tests (e.g., within regional health information organizations, RHIOs) and in relevant models with smaller international partners so that potentially innovative advances can be demonstrated

Table 1.2 Challenges and unique needs in military information science research

• New science model (interdisciplinary "convergence") where life science projects include nontraditional expertise in mathematics, physics, and engineering
• New methodologies to conduct research where the advances in technology are outpacing the completion of conventional studies (e.g., increase use of prototypes and field demonstrations)
• Common development environments are essential DoD research capabilities and interoperability is a key consideration from the outset of the research
• Partnerships with other military agencies in overlapping nonmedical technologies such as communications, decision support tools for commanders, and robotics to ensure congruence and efficiency
• Cultivation of new extramural capabilities (academia, industry, other governmental) to conduct militarily relevant research in medical training and predictive models and tools
• Development of new military champions ("receptor sites") for smooth transition of findings into use and system/policy integration by material and doctrine developers
• Partnership with industry in new acquisition models involving commercial sector acceleration of advanced development and sustainment
• Collaboration with military users (e.g., warfighters, medical care providers) to develop relevant solutions and promote collaborative innovation that comes from the user community as the user community is changed by the technology
• Time lag to complete and receive approval from the Defense Business Certification Process before expanding research efforts beyond the prescribed monetary limits

before they are steamrolled out of existence in a big bureaucracy (i.e., the Schumacher concept of “smallness within bigness”).

Research must be conducted in partnership with nonmedical technology communities in the military, in industry, and with the warfighter (e.g., development of an effective electronic health record (EHR) system needs participation of enterprise system managers, information technology specialists, as well as medical users and patients). Because military medicine is lagging behind the rest of the DoD in information science applications, solutions need to take advantage of and not reinvent what has already been established in the nonmedical communities, including intelligence data analyses, military communications protocols and networks, advanced distributed learning co-laboratories, and learning and training methods and metrics.

The military medical community lacks a proponent office for formulation of requirements, policies, and implementations of new capabilities developed out of information sciences (e.g., medical training and curriculum standardization; and telemedicine offices). The only transition paths that were available within the DoD for JPC1 research findings and advanced development were via the Army Program Executive Office (PEO) for Simulation, Training, and Instrumentation (e.g., medical training manikins) and the PEO for Joint Medical Information Systems.

As a new research effort, the JPC1 has the opportunity to be based on a new understanding of the most effective approaches to promoting innovation and maximizing research efficiency. A key aspect of innovation is the recognition that end users, not industry or bureaucratic acquisition models, are the source of most technological innovation [8]. This has been especially true in medicine, with medical care providers promoting the development of the technologies they needed rather than accepting industry models of medical needs (e.g., development of the heart-lung machine). This calls for information science research models that involve participative innovation [9], with user involvement as well as careful consideration given to trends in user and societal adaptation to technological advances. A more specific example is to put new tools in the hands of medics and conduct Joint Capability Technology Demonstration (JCTD)-type experiments to find out how they choose to use or modify, and how they themselves adapt to, the new capabilities.

1.4 Innovation and Disruptive Technologies

Three key innovators highlight the challenges in information science and technology from three perspectives. Colonel Ronald Poropatich spent an Army career developing telemedicine technology solutions to solve urgent warfighter problems [10]. These range from early efforts in Bosnia on Primetime III medical video teleconferencing and teleconsultation, to later high priority efforts in telebehavioral health based on cell phone connectivity between patients and their case workers in CONUS, as well as extensive telemedicine efforts in Afghanistan and Iraq. These

Army-funded demonstration projects provided near-term fixes to real medical information problems, benefitting many soldiers and advancing the use of everyday technologies to solve remote location military medical problems. His greatest challenges were in promoting the adoption of disruptive technologies in a large bureaucracy with an impressive resistance to change. With new affordable technologies and the persistence of a few dedicated scientists, telemedicine was finally being recognized and accepted as equivalent to face-to-face encounters and sought as an effective and needed modality to deliver health care while implementation policies and requirements lag behind.

Colonel Hon Pak established business models and test and implementation processes to provide transition points, policies, and vital infrastructure for telemedicine research, originally pioneering teledermatology research as a model of telemedicine including a series of studies to consider image quality requirements and other procedural issues [11, 12] and creating the common development environment at TATRC to provide the DoD with their only electronic health record sandbox [13]. The TATRC-sponsored Morningside initiative is an example of the process-organizing efforts for electronic health record data utilization [14]. These efforts helped to move telemedicine and health information technology into a recognized military medical specialty, with its own proponency and as a lead set of solutions to reduce future health care costs and increase patient safety.

Jaques Reifman spent more than a decade promoting the use of mathematical modeling solutions to military medical problems, collaboratively developing decision support, analysis, and planning tools with all interested and capable DoD medical research scientists. The greatest challenge was to gain recognition for computational biology as an important but overlooked research entity rather than to be treated as an afterthought statistics service. Winning rigorously competitive grant awards for high-performance computing applications in the DoD, medical decision support tools, and basic network science investigations, Dr. Reifman brought medical research across the Services into a modern era of convergence science on virtually every important topic of militarily relevant information sciences. He led the development of military medical informatics research strategies and then ensured their execution [15–17]. There are three examples of the influential proponents (research zealots) that are required in the advance of almost any major new research idea. They provided a solid foundation for the new JPC1-funded effort.

Disruptive innovations improve a service in unanticipated ways, usually by lowering costs or changing customer access [18]. Examples of disruptive technologies affecting military medicine include smart phones and other personal mobile communications technologies, cloud computing, ultra high-speed broadband networks, high-performance computing, and semantic web technologies. The affected markets include many conventional practices, infrastructure, and research models. Disruptive technologies are new to standard operating procedures, existing plans, and the research requirements established by an earlier generation not raised with the new communications and computing technologies. Truly disruptive processes and technologies in the DoD are typically not synchronized with the military customer or even the requirement processes because revolutionary (rather than evolutionary) advances are unpredictable and provide unanticipated advantages and consequences. Henry Ford reputedly stated that "if I had asked people what they wanted, they would have said faster horses." This exchange with a military requirements team might have gone further: "why do you want a faster horse?" "To evacuate casualties faster." "So you don't necessarily want a faster horse; you want a better way to rescue and transport casualties." The solution then could be an advanced transportation option or even a particle tele-transporter, if it were available. If we have an alternate solution such as an unaccompanied aerial vehicle casualty evacuation system, we can do other unanticipated things like recover casualties in dangerous and remote settings without a medic [19]. That is disruptive to the current investment in medic force structure and training, but it may lead to greater effectiveness on the battlefield and the advantage should not be dismissed simply because it was not in the 10 year technology forecast.

Disruptive technologies and processes such as the internet could have fundamental effects on how we organize traditional military chain of command because of the change in access to information. Nevertheless, these new approaches provide advantages to an agile and efficient military and net-centric warfare has been embraced by the Army as the way-ahead. For military medicine, this ready access to information empowers patients and has propelled the shift to a more effective patient-centered medicine paradigm, where the individual takes primary responsibility for their health, and a new emphasis is placed on wellness, prevention, and personalized medicine. It also can provide enhanced medical situational awareness, ranging from real-time warning of change in health status to military units and their exposure risks, and providing casualty data for the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) system [20], affecting near real-time adjustments in tactics and procedures. The JPC1 program was intentionally focused on 6.3 and 6.4 late stage research and development and advanced development strategies to embrace these advantages and reduce risk in the implementation.

1.5 Research Strategy: Current and Projected Research Priorities

Military requirements, external drivers (Table 1.1), and strategic plans largely shape the key research priorities for the JPC1. A summary of mission priorities are listed in Table 1.3. These are enduring needs and problem sets relevant to military medicine, not technology forecasts or specific technologies and systems. Technical workgroups composed jointly of subject matter experts and program managers are best positioned to establish these priorities.

Technology roadmaps and strategic plans had been created in this area for more than a decade. Until this program, these were simply research visions without resources and without clear transition partners. The 1994 Army Science and Technology (S&T) Vision and Strategy Review by the ASTAG highlighted Army

Table 1.3 JPC1 research priorities

• Develop metrics for development and validation of medical training simulations
• Investigate solutions to replace the use of animals in military medical training
• Conduct research to establish and predict clinical competency
• Form strategies to monitor and sustain medical competencies in coordination with professional medical organizations
• Create publicly available advanced technology developer tools to enable sophisticated interactive medical education (e.g., interactive virtual human technology to enable realistic natural language-simulated interviews and experiences)
• Create new options for advanced distributed learning for just-in-time and refresher medical training
• Develop remote technologies and applications for "patient centered medical home" to promote individual responsibility for health and healing and to reduce hospitalizations
• Demonstrate benefits of medical technologies and telemedicine (including mobile health) to improved efficiency and reduced costs in health care delivery for the warfighter
• Develop semantic web tools and strategies for seamless management of medical data across medical information systems
• Advance strategies to address interoperability, security, and privacy issues to make everyday technologies (e.g., smart phone, webcam) serve patient and provider needs
• Provide options for medical data acquisition and clinical decision support from point of injury through all levels of medical care
• Develop and apply analytical tools to aggregated electronic medical data to enhance patient safety and reduce costs in the Military Health System
• Construct decision support tools for near real-time analysis of physiological sensor data for medical status of soldiers (e.g., dehydration, neurocognitive status, mission readiness)
• Create mathematical models of biological data to provide planning tools for materiel and combat developers (e.g., load carriage and musculoskeletal injury models; metabolism and energy balance; concussive brain injury and neuroimaging)
• Devise high-performance computing applications to accelerate discovery science efforts in the DoD (e.g., in silico models of biological processes and organisms for virtual identification and testing of candidate medical treatments)
• Collaborate with other DoD and federal agencies in information science research and development particularly with the VA on interoperability (e.g., Nationwide Health Information Network (NwHIN) and Health Information Technology Innovation and Development Environments Subgroup (HITIDES))

telemedicine systems that would be completed "within 1–2 years": personnel status monitor, smart litter/trauma care pod, digital x-ray, electronic dog tag, and interactive telepathology (George Singley, briefing to the ASTAG, October 1993). Of these, only the digital x-ray and telepathology efforts were implemented; the electronic dog tag, personal status monitor, and smart litter were eventually technical successes, but are still not in general use.

In 2001, TATRC sponsored a large strategic planning meeting and published recommendations for strategic research investments in information science [15]. Four of the five thrust areas currently encompassed by the JPC1 were addressed, with medical simulation training included within the computational biology roadmap. Separate strategic planning was conducted for medical simulation training in 2000 [21] and again in 2008 in the larger context of the Hospital of the Future [22]. Other strategic plans were developed and published for knowledge engineering, specifically for medical situational awareness for bioterrorism and epidemic disease threats [17], for soldier physiological monitoring systems [16], the Morningside Initiative [14], and the EHR way-ahead [23]. Action on these strategies was limited not by plans but by resources. TATRC used these plans to shape Congressional special appropriations and other sources of funding to address these priorities to the maximum extent possible [13].

1.6 The Research Program

Ultimately, JPC1 activity is driven by the available budget. The majority of the initial JPC1 core funding in FY10 and FY11 was allocated for the first of the five mission thrust areas, medical simulation and training. Thus, the major research efforts fall in this portfolio.

1.6.1 Medical Simulation and Training Systems

Military training systems have been supported by mature research and development programs in each of the military services. This includes the use of sophisticated simulation technologies and advanced distributed learning networks. In sharp contrast to much of the rest of the DoD, medical training simulations lag behind. In the past decade, most medical simulation efforts have been supported only intermittently through special programs (SBIR and congressional special interest) [13]. High visibility interest in reducing the use of animals in medical training accelerated interest in this area in the US as well as numerous NATO partners (this was one of the primary discussion topics for NATO Panel 215, “Advanced Training Technologies for Medical Health Care Professionals”). The overarching goal of the JPC1 effort was to create simulation-based medical education programs for the military that will enhance patient safety, reduce medical costs, and expand access to effective training as well as individual health care empowerment. This involves bringing current technologies involving advanced distributed learning, smart phone and other mobile systems, serious games, and virtual reality into military medical applications. The strategy was to move military medical training to a curriculum-aligned, metrics-driven, objective system to train and assess proficiency of skills. A key part of the research strategy was also to benefit from the lessons learned about interoperability standards and training metrics in the nonmedical community.

In the JPC1 program, a Medical Training Systems workgroup was formed under the leadership of Thomas “Brett” Talbot. This intramural group was composed of medical training and simulations subject matter experts and nonmedical learning and simulation research program managers from across the services. The group evolved

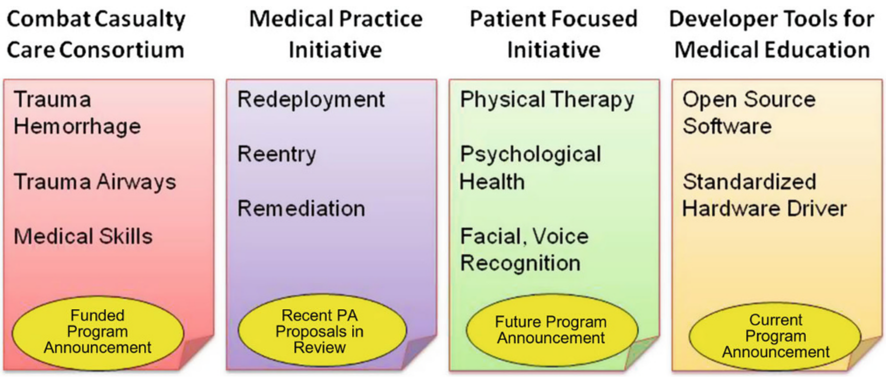

Fig. 1.2 Four research thrust areas in the DoD medical simulation and education program, with findings and solutions integrated through the Armed Forces Simulation Institute for Medicine (AFSIM)

a research strategy that centered on three different user communities (prehospital care providers, medical care specialty providers, and beneficiaries) and with a fourth initiative on the development of common simulation developer tools (Fig. 1.2). The Combat Casualty Training Initiative was addressed through a competitive solicitation that resulted in several major university grants to address different parts of the evaluation of simulations for combat casualty care training priorities. These grants and several other funded projects were also intended to investigate the use of simulation for key combat medic skills such as hemorrhage control and airway management, and to evaluate replacement of live animals in medical training for procedures such as cholinergic crisis. Related JPC1 projects addressed specific training simulation options for special forces' medic training, advanced simulators for massive hemorrhage and amputation, and the Army combat medic training program.

A solicitation for the "Medical Practice Initiative" focused on the problem of specific skills degradation in redeployed providers. This research supported the larger strategic goal of developing a comprehensive system of automatic monitoring, evaluation, and training sustainment through the military lifecycle of care providers ("Continuous Observation of Medical Records for Advanced Doctor Education", COMRADE) that would eventually link EHR data with an intelligent assessment and tutoring system for individual providers. Many previous TATRC workshops were exclusively centered on the topic of surgical skills development and assessment for physicians, especially with the visionary leadership of Rick Satava [24]. This was a logical starting point for medical training simulation research, especially for technology-enabled surgical procedures such as those involved in laparoscopic surgery that could be readily simulated, provide similar views and haptic feedback compared to the actual procedures, and could be scored through the motions of the manipulators. The JPC1 moved to a broader strategy to serve medical training priorities in the DoD and not be limited to surgical specialties where certification of skills is already governed by national specialty boards and societies.

The Patient-Focused Initiative was intended to enhance user interfaces and interactive technologies for patient medical training empowerment, including education, access, and rehabilitation. This initiative also continued funded efforts in the development of virtual human technology at the Institute of Creative Technologies, in collaboration with CAPT Russell Shilling's "Detection and Computational Analysis of Psychological Signals (DCAPS)" DARPA program on behavioral cues from facial expressions, posture and activity, voice stress and speech content, sleep patterns, social interactions, and online activities that may lead to diagnostic aids and also provide more realistic virtual humans for training and other applications (http://www.darpa.mil/Our_Work/I2O/Programs/Detection_and_Computational_Analysis_of_Psychological_Signals_(DCAPS).aspx). The TATRC investment in ICT's SimCoach (interactive avatars that are expected to be used as patient-focused behavioral health advisor tools and trainers) continued with expansion of natural language processing capabilities for a more realistic personal interaction with an avatar (Fig. 1.3). A project with the Armed Forces Medical Museum explores interactive technologies for public education in neuroprosthetic and brain-machine interface technologies being developed by the DoD.

The US Army Medical Institute of Chemical Defense (USAMICD) has been a DoD leader as an end user of simulation for specialized curriculum enhancement. This laboratory pioneered significant advances in serious games training technologies to create "activated" learning. For example, Nerve Academy was a multimedia curriculum for nerve agent education that includes live animation demonstrations, a virtual instructor, and dynamic exploratory exercises. This covered principles of nerve conduction, effects of nerve agents, nerve agent casualty treatment, and

Fig. 1.3 Bill Ford, one of the sets of virtual human prototypes developed for the military, is designed to attract and engage soldiers and family members with the goal of empowering them to take responsibility for behavioral health and to break down barriers to seeking available diagnostic and therapy resources. This is an example of research under the Patient-Focused Initiative education and training effort. Illustration courtesy of Dr. Skip Rizzo, Institute of Creative Technologies, University of Southern California

advanced topics in nerve agents and included self-assessment tests. Nerve Academy was a semifinalist for the 2009 AdobeMAX award. SIMapse 3.0 was a nerve agent pharmacology simulator that kinetically portrays the behaviors of nerve agents, effector organs, and antidotes in a free-play live simulation. It accurately depicts all major unclassified nerve agents and a wide variety of antidotes used throughout the world. It included speech capability, live classroom demonstrations, and a scenario authoring tool using the TOXIC scripting language. Also included was a full laboratory book containing a curriculum of 28 progressive lessons designed to instill graduate level knowledge in nerve agent pharmacology. Other novel simulators provide specific chemical defense training (USAMRICD Cynanide Casualty Simulator; Chem Squares 2.0). CBRNE GAME (Breakaway Ltd.) was an online multiuser mass casualty simulator for civilian chemical casualties modeled after the USAMRICD Hospital Management of CBRNE incidents course to allow real-time simulated CBRN casualty events.

A fourth initiative, Developer Tools for Medical Education, supported development of a tri-service open platform for simulation at USUHS, building on the previous research efforts at the National Capital Area Medical Simulation Center (NCAMSC), as well as developing open source physiology models to drive training simulations (Fig. 1.4). One goal of this effort was to have an effective multiplayer distributed training system for team training in medical procedures (an international military demonstration project was planned within the NATO HFM-215 panel).

Training simulations require scientifically based metrics for design and evaluation of effectiveness. Standardized metrics were developed through a series of workshops organized by the Office of Naval Research with academic partners at the National

Fig. 1.4 Virtual cricothyroidotomy and unified surgical simulation platform for medical readiness training created by Alan Liu at the National Capital Area Medical Simulation Center (NCAMSC). This demonstrates a simple medical procedure involving psychomotor skills that can be trained with a common platform involving a computer and haptic manipulators. Illustration courtesy of Dr. Alan Liu (http://www.simcen.org/cric.html)

Center for Research on Evaluation, Standards, and Student Testing (UCLA) on behalf of the JPC1. The first workshop focused on the individual measures and technical quality components for simulation performance assessments; subsequent workshops target practice and certification issues and team competencies.

A major investment in basic research was made from the FY10 budget to study the role of olfaction, emotion, and learning plasticity at the Monell Chemical Senses Center (Philadelphia, PA). This began to address a fundamental gap in understanding the significance of olfaction in neurological health and learning and the use of odorants in enriched environments and training, including medical simulations.

All of the medical simulation training efforts were coordinated through the Armed Forces Simulation in Medicine (AFSIM) center at TATRC, including execution and integration of many of the JPC1-funded projects in this portfolio. Major capabilities for military medical training simulation test and development included the Anderson Simulation Center at Madigan Army Medical Center (Tacoma, WA), a significant tri-service presence in Orlando in modeling and simulation RDT&E (including RDECOM), the Institute of Creative Technologies (an Army University-Affiliated Research Center in Los Angeles, CA), and the consortium established under the DARPA DCAPS program.

Other successes were supported through DoD SBIRs and Congressional Special Interest funding. These earlier projects generally fell into four categories of training technologies: personal computer-based interactive multimedia, digitally enhanced manikins, virtual workbenches, and total immersion virtual reality. Of the 175 medical simulation projects that had been funded by TATRC in the previous decade, the majority of the projects were industry-led and focused on technology development [25]. The new core-funded program was able to move from pure technology development to a longer-term strategic plan addressing fundamental issues such as interoperability, metrics, curriculum, and user interfaces.

Through the CIMIT program in Boston, Massachusetts, manikin trainers were developed, including a smallpox inoculation training system; VIRGIL, the chest trauma training simulator; and COMETS, a next generation autonomous manikin. VIRGIL was a physiologically realistic mannequin designed to train first responders to perform chest tube insertion and prevent a leading cause of battlefield deaths (Fig. 1.5). One of the Army's Greatest Inventions in 2004, it was also used to demonstrate what was possible in medical simulations in a 2008 Wellcome Trust Museum exhibit on War and Medicine. It was compared favorably in a pilot test of USUHS medical student performance in chest tube instruction with live pigs (Col. Mark Bowyer, personal communication, 2008). The VIRGIL technology became a component of the COMETS manikin. COMETS technology was licensed by the Army to CAE and marketed as CAESAR, an interactive, full body-trauma casualty system that behaves autonomously to provide realistic training for Army medics and civilian first responders. The autonomous features are intended to reduce the instructor training load and the system can be adapted to changing training requirements. COMETS was developed out of a multiyear project at Massachusetts General Hospital/CIMIT with joint TATRC and Combat Casualty Care funding [26, 27]. The manikin provided medical simulation training for massive hemorrhage,

Fig. 1.5 The VIRGIL chest tube trainer developed in the Steve Dawson simulation laboratory at CIMIT/Massachusetts General Hospital. This demonstrates a part task trainer involving a PC-based graphical interface that tracks the internal position of chest tubes during training, providing a repeatable training experience superior to the use of live animals (Mark Bowyer, unpublished research results). Basic concepts of the VIRGIL system have been incorporated into the more comprehensive autonomous COMETS, now CAESAR, human manikin. Illustration courtesy of Dr. Steve Dawson

pneumothorax, limb amputation, airway management including cricothyrotomy, and had realistic skin and eyes, multiple pulse points, and intravenous access. Another JPC1 project expanded the craniofacial simulation with emphasis on an ophthalmic trauma trainer with an embedded assessment of competency.

Other examples of projects include the development of a DVD trainer to instruct deploying physicians on compartment syndrome management, funded from the TATRC innovation program as an urgent warfighter need, and a compartment syndrome training simulator. The Wiser Institute (Pittsburgh, PA) continued a large challenging longitudinal study to assess the skill levels for management of the three most prominent battlezone injuries for combat medic trainees and of veteran combat medics at the Medical Education and Training Campus (METC) (http://www.metc.mil/). From this evaluation, recommendations were made for the use of simulations in medic training. Examples of the many efforts that have been funded in this portfolio have been summarized in a previous TATRC Report [13] and in a careful portfolio analysis [25].

Other related efforts have moved into preventive medicine training for individuals such as the internet-based weight management system developed at the Pennington Biomedical Research Center and included a longitudinal study now being tested with the Louisiana National Guard [28]. Similar technologies including the use of the online tips, encouragement, and reminders have been extensively tested by COL Vigersky in the WRAMC diabetes program [29, 30]. A joint

NIH-TATRC-sponsored symposium was held on the use of virtual reality technologies for research and education in obesity and diabetes [31] and this was also highlighted in an international workshop in Warsaw, Poland, several months before. Simulation technologies and health information technologies carry huge potential as enablers in health risk communications research and related preventive medicine strategies currently pioneered in nursing research and other allied health sciences.

A unique opportunity in advanced distributed learning that spans several JPC1 portfolio areas was an FY10 awarded Coalition Warfare Program (CWP) project on Mobile Learning Environment (MoLE). This TATRC-supported, and later JPC1-supported, project was led by Naval Forces Europe/Africa and included more than 20 international partners in an effort to deliver mobile medical courseware such as just-in-time training and refresher training in support of humanitarian relief mobilization efforts. The CWP project included technical trials of the leading smart phone and other operating systems, development of integrated mobile learning capability, evaluation of mobile courseware by DoD and international partners, and identification of technical challenges to cross-cultural adoption of m-learning. This project could implement features of the GuideView project, a program jointly supported by TATRC and NASA to develop just-in-time medical training and decision support on mobile devices [32]. The concept was also expanded with JPC1 support to produce a state-of-the-art electronic version of the Special Forces medic handbook for SOCOM.

1.6.2 Mobile Health ("M-Health") and Telemedicine

Telemedicine support to Operation Joint Endeavor in Bosnia in 1996 ("Primetime III") marks the start of TATRC proof-of-concept telemedicine field demonstrations. Primetime III explored the use of communications technologies in medical consultation and the efficient transfer of radiological images between medical providers [33, 34]. Expansion of telemedicine capabilities in subsequent deployments was supported through the Army Operational Telemedicine Program under the leadership of Colonel Ron Poropatich [10]. In 15 years, technology advances, along with the public embrace of increasingly affordable and useable electronic devices, moved telemedicine from unwieldy, expensive, operationally complex systems that originally imposed an unacceptably large deployment footprint to an enabler with clear advantages demanded by a new generation of medical providers (e.g., email, cell phones, smart phones, webcams) (Fig. 1.6). The technology implementation had been limited primarily by security, privacy, and procurement issues and policies. These issues were each addressed in subsequent demonstration projects and experiments. The major JPC1 research questions involved evaluation of the quality of the medical encounter, access to care, and capturing data from the encounter in the medical record.

Using the existing Army Knowledge Online secure email system, the teleconsultation program was initiated for remote dermatology consults in 1994

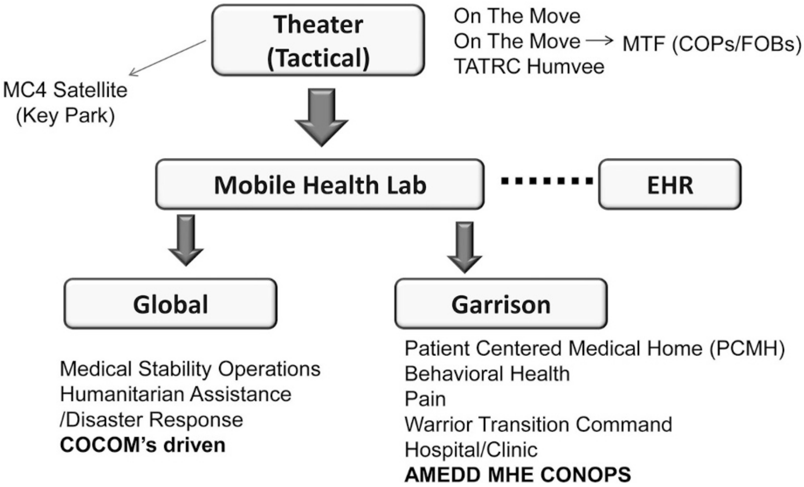

Fig. 1.6 Mobile Health (m-Health) is ubiquitous, with important applications in theater, in garrison, and in international and humanitarian operations. In the TATRC m-Health testbed, all of these interactions are tested collaboratively with the Army's Medical Communications of Combat Casualty Care (MC4), the Army Battle Command Battle Lab-Gordon, and the Communications-Electronics Research, Development and Engineering Center (CERDEC)

[35]. The concept was simple, allowing email requests with attached JPEG images to be sent by a remote provider into the unencrypted system (no personal identifying information included in the text or the images). These requests are answered by an on-call specialist within 6 h for urgent requests and 24 h for routine requests. This program has expanded to more than 19 medical and seven dental specialty services and currently include heaviest use in dermatology (43%), infectious disease (8%), orthopedics (7%), and neurology (6%), with a total of 9285 consults to theater serving more than 2292 deployed provider users since its inception (personal communication, Francis McVeigh, July 2011) [36, 37]. Consults have been answered in an average of 5 h and 8 min by a rotating call roster of providers spanning multiple time zones. One fourth of the consults have been requested by Air Force and Navy providers. Teleconsultation referrals have resulted in prevention of more than 110 unnecessary evacuations (estimated cost avoidance of $4 M) and facilitation of 415 cases of appropriate evacuations. AKO teleconsultation services were extended to all NATO forces in 2008 and are available to all NATO sites in Afghanistan [38].

The operational telemedicine research program supported medical communications demonstration projects in each of the Combatant Commands (COCOMs), including the previously discussed Coalition Warfare Program Mobile Learning Environment (MoLE) project, and vitally important theater telebehavioral health efforts. At the start of the Operation Enduring Freedom/Operation Iraqi Freedom (OEF/OIF) deployments, limited medical bandwidth was addressed with a Joint Urgent Operational Needs Statement (JUONS) request, following TATRC experiments with the Army Communications Battle lab. This permitted projects such as the first demonstration of in-theater surgical telementoring by T. Sloane Guy in 2009 in Iraq. He used a system with adjustable camera and laser pointer attached to an overhead surgical light with integrated audio. This was initially developed and tested in teleproctoring of three clinical scenarios in collaboration with San Francisco VAMC [39]: a penetrating right ventricular injury, an open tibial fracture, and a subdural hematoma requiring craniectomy. Telebehavioral health projects were well-received by in-theater users and standardized across Afghanistan, Iraq, and Kuwait with over 80 sites providing VTC connectivity via Secure Internet Protocol Router Network (SIPRNet) to remote patients and providers to improve access to behavioral health care. Encounters were documented through the Armed Forced Health Longitudinal Technology Application-Theater (AHLTA-T). Evaluations indicated savings accrued in reductions in travel through remote medication management and combat stress management (personal communications, COL Ron Poropatich, July 2011). The most important discoveries from these experiments were the overwhelming acceptance and the user innovations in improving access to care, confirming the truism that end users are the ultimate innovators. This included factors such as improved patient willingness to use behavioral health services because of a reduction in social stigma and easier access to providers, and improved efficiency in extending the reach of a limited number of behavioral health providers. These findings directly led to General Chiarelli's successful request to Congress to legislate the STEP Act, permitting DoD telebehavioral health services across state lines.

Research and development in military medical logistics addressed telemedical maintenance, medical supply tracking systems, and deployable medical communications units. Telemedical maintenance of CT scanners in theater began as a TATRC-funded experiment that has resulted in comprehensive "virtual engineering" maintenance support in Iraq, Afghanistan, and Kuwait, connected to Landstuhl Army Medical Center. Other efforts include support of teleradiology solutions including the Theater Image Repository (TIR), addressing the lack of centralized acquisition of all in-theater images. Tracking of medical logistics was a major challenge again in the Haiti earthquake relief effort. The Rugged Mobile Logistics System (RMLS) (VerdaSee Solutions, Inc., West Langhorne, PA) was a combination of hardware- and software-integrated solution developed into a GPS-enabled system for medical communications including locating RFID tags on medical supply pallets. This was one of the families of sophisticated medical asset tracking systems managed by TATRC.

In 2008, a new focus on traumatic brain injury (TBI) and posttraumatic stress disorder (PTSD) provided funding through TATRC to initiate the Army tele-TBI program. Three initiatives were launched: develop an Army Medical Department (AMEDD) Tele/TBI/health network; deploy transcranial doppler capabilities to Army medical centers; and develop a cell phone secure messaging system (mCare) to communicate with Community-Based Warrior Transition Unit (CBWTU) soldiers, their platoon sergeants, and their case managers. Francis McVeigh, O.D., oversees these three initiatives and directly manages the teleTBI/health network program from TATRC. The teleTBI/health network initiative provided equipment and personnel for the regional medical centers and their medical treatment facilities to establish and sustain telehealth video teleconferencing. This AMEDD TeleTBI/health Network includes 60 sites throughout five regional medical commands involving 76 support personnel who provide telehealth encounters in 22 medical specialties (behavioral health, echo-cardiology, dermatology, TBI, neurosurgery, pain management, and others). Greater than 75,000 telehealth encounters have been performed since FY10 (personal communication, Francis McVeigh, September 2011). Ongoing evaluation of the program estimates at least $5 M in cost avoidance by reducing travel and other costs, more rapid access to care averaging up to 30 days sooner in some locations, better leveraging of resources across regional medical commands, and greater than $2 M/year return on investment just from Northern Regional Medical Command's neurosurgery teleconsultations [40]. Telehealth network initiatives used the Extension for Community Health Care Outcomes Model for telepain and teleTBI. This model used a team of subject matter experts at a hub who reach out to rural/remote clinics via video teleconferencing modalities. The remote/rural providers presented multiple cases and received consultative advice and continuing education during the sessions. This method increased rural/remote providers' medical knowledge, promoted standardization of care, and reduced unnecessary travel for providers and patients. The Transcranial Doppler program (TCD) supported neurotrauma management to detect and treat cerebral ischemia from severe TBI-associated vasospasm. The program provided over 1376 TCD studies as of August 2011, contributing to pharmacological management of 72% of the patients and necessary follow-up procedures for 18% (personal communication, Francis McVeigh, September 2011).

The mCare Initiative was a significant demonstration effort that was elegant in its deceptive simplicity. There was an identified need to increase communication between soldiers who are spread out among multiple states in civilian communities with their case managers and their platoon sergeants. mCare connected injured warriors with their case workers at the Community-Based Warrior Transition Units (CBTWUs) utilizing the Soldiers' personal cell phones by sending secure messages (Fig. 1.7). mCare was recognized as one of the Army's Greatest Inventions of 2010. The project demonstrated that personal cell phones could be used as a secure bi-directional Health Insurance Portability and Accountability Act (HIPAA)-compliant messaging system within the military health care system, managed by a central, secure web portal. Over 138,000 secure messages were sent (personal communication, Holly Pavliscsak, September 2011). Messages remind patients of appointments and disseminate administrative, health, and wellness information. mCare also assists case managers by gathering important information about patients and providing real-time alerts for critical issues. The challenges in this demonstration project were to ensure open architecture and software that would operate on all major cell phone systems, address issues of internet security and patient privacy, and address changing regulatory and bureaucratic requirements such as the Defense Business Certification process approval to expand the project beyond prescribed monetary limits.

Fig. 1.7 The mCare program connects military providers and patients by secure messaging on the soldiers' personal cell phone, increasing access to care and extending the reach of a limited number of medical providers. This program was recognized as one of the 2010 Army's Greatest Inventions

A JPC1-funded study conducted by the National Center for Telehealth and Technology (T2) (Fort Lewis, WA) explored barriers to in-home telebehavioral health patient encounters that would allow a soldier to conduct a virtual clinic visit with a provider by personal webcam from their own home. The purpose of this capability was to improve nonstigmatizing patient access to mental health resources. Barriers to implementation included establishing the quality of telehealth encounters and unattended patient safety, as well as communications security and privacy issues, recording the encounter for the medical record, and interstate licensing issues for providers.

Multiple studies on store-and-forward approaches were conducted, with many specialties involved, ranging from TATRC-funded projects on pediatric tele-cardiology, e-ICU efforts [41, 42] in the Pacific rim, to teledermatology, to telepsychiatry through the Walter Reed telehealth services center [43]. These studies were concerned with cost-effectiveness compared to current standards of care and reliability when used in military applications. Telepathology was an early TATRC telehealth demonstration project that has since been implemented as a standard of practice [44]. Large investments over more than a decade in remote diabetes monitoring and management, including telediabetic retinopathy, have been a model of chronic disease management through telemedicine. A web-based chronic disease management and communication system called MyCareTeam was developed at the ISIS Center at Georgetown University. Clinical studies of MyCareTeam showed statistically significant improvements in glycosylated hemoglobin (HbA1c) for patients who used the technology compared with those who chose not to use it [45, 46]. The studies also showed that personal and frequent communication between provider and patient resulted in frequent patient use of the technology and a significant improvement in HbA1c [47–49]. A large series of projects by COL Robert Vigersky explored simple technology aids such as cell phone reminders, patient decision support tools, and cell phone dietary management with food photography to improve diabetes care and prevent costly hospitalization readmissions [29, 30, 50, 51]. A TATRC workshop in 2007 explored the application of these technologies in a potential Hawaii and Pacific Islands telehealth model in a remote geographically distributed population [52], and outreach studies for similarly remote and underserved populations such as native American veterans were explored, including cultural generalizability of neuropsychological tools.

Point of injury casualty data acquisition and medic decision support systems have been the topic of various high visibility telemedicine efforts for more than 20 years, notably the electronic dog tag ("EIC" and "WEIC"), a handheld medical data collection system ("BMIST"), and multiple versions of casualty physiological monitoring systems ("WPSM"). These systems developed by TATRC were named Army's Greatest Inventions, but, for various reasons, these early efforts have not gained traction as medic tools. Eventually, the TEMPUS Pro system was selected as a candidate technology for the Joint Forces Command (JFCOM) and Joint Medical Distance Support and Evacuation (JMDSE) JCTD. This was intended to be used by combat medics for casualty monitoring, point of injury data acquisition, and telementoring. The system generated a digital Tactical Combat Casualty Care Card record of patient encounters, provided voice, physiological data, and still photo or video transmission for telementoring, and transmitted medical information over secure tactical networks from forward deployed medics to supporting medical treatment facilities and ultimately to update AHLTA and Theater Medical Data Store (TMDS) (Fig. 1.8). Following use in field training environments, the 1/25th Stryker Brigade Combat Team (BCT) submitted an operational needs statement to use the system during deployment to Afghanistan. Secure tactical radio integration was also demonstrated in Net Modernization exercises, and the system was nominated for evaluation in an Army Network Integration Exercise. The Tempus system was championed by United States Army Special Operations Command (USASOC) and the Marine Corps Warfighter Laboratory and development continued with JPC1 support [19]. This effort continued as a JPC1-funded Warrior Medical Network ("MedNet") project to develop standards-based data capture from medical devices at the point of injury with storage in AHLTA-Theater (Fig. 1.9).

1.6.3 Electronic Health Record and Health Information Systems

The advantages of an electronic health record (EHR) over paper records are accrued through the information that can be garnered from aggregated patient data, in addition to all the advantages to the individual patient and providers that come from convenient access to complete medical records. The EHR is a disruptive

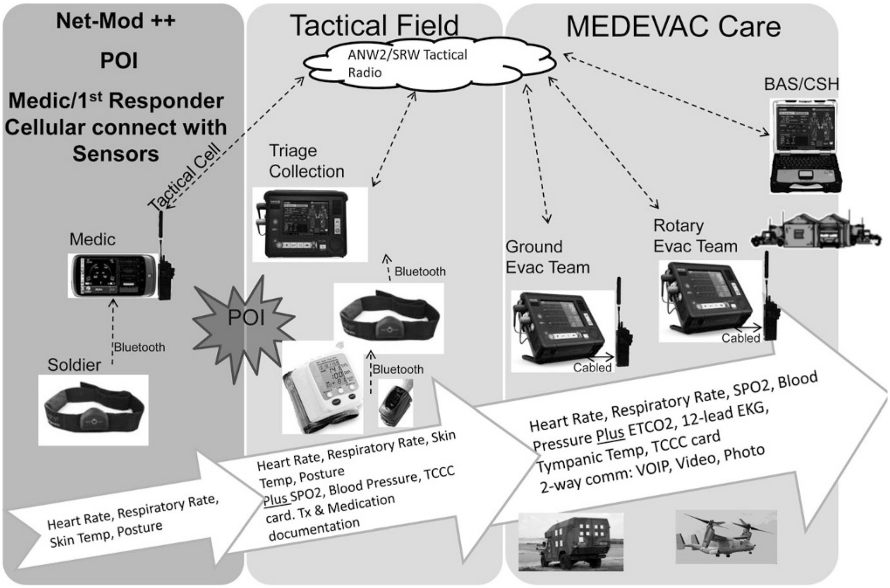

Fig. 1.8 The Tempus-Pro system was identified as a point of injury medical monitoring system through downselection of candidate technologies in a JCTD and in subsequent field studies and network integration experiments, resulting in early technology adoption by SOCOM and the Marine Corps Warfighter Laboratory. The system generates a digital TCCC record of patient encounters, provides voice, physiological data, and still photo or video transmission for telementoring, and transmits medical information over secure tactical networks from forward deployed medics to supporting medical treatment facilities and ultimately to update AHLTA and Theater Medical Data Store (TMDS). Experiments now are focused on how to acquire and collect minimally intrusive point of injury data and monitor a casualty through evacuation

technology since it changes so many current practices regarding medical information access, empowering patients and providers in ways previously unimagined. The Office of the National Coordinator (ONC) for Health Information Technologies (HIT) was established in 2004 to promote and standardize an electronic health information use and exchange. TATRC worked in close coordination with the ONC and supported the PEO-Health Information Technology at Tricare Management Activity (TMA), with Army-funded support for demonstration projects and by leveraging Congressional special appropriations. The Armed Forces Health Longitudinal Technology Application (AHLTA) is the world's largest EHR, supporting over 9 million beneficiaries in treatment facilities around the world, including deployed environments and on-mobile devices to support real-time medical record keeping. This offers massive power in early detection of new deployment health threats, adverse drug responses (e.g., pharmacovigilance program), or for refining cost-effective standards of care. As the system improves, it will meet the Army Surgeon General's (TSG's) key objectives to provide timely, accurate, and actionable information for providers and the medical health system.

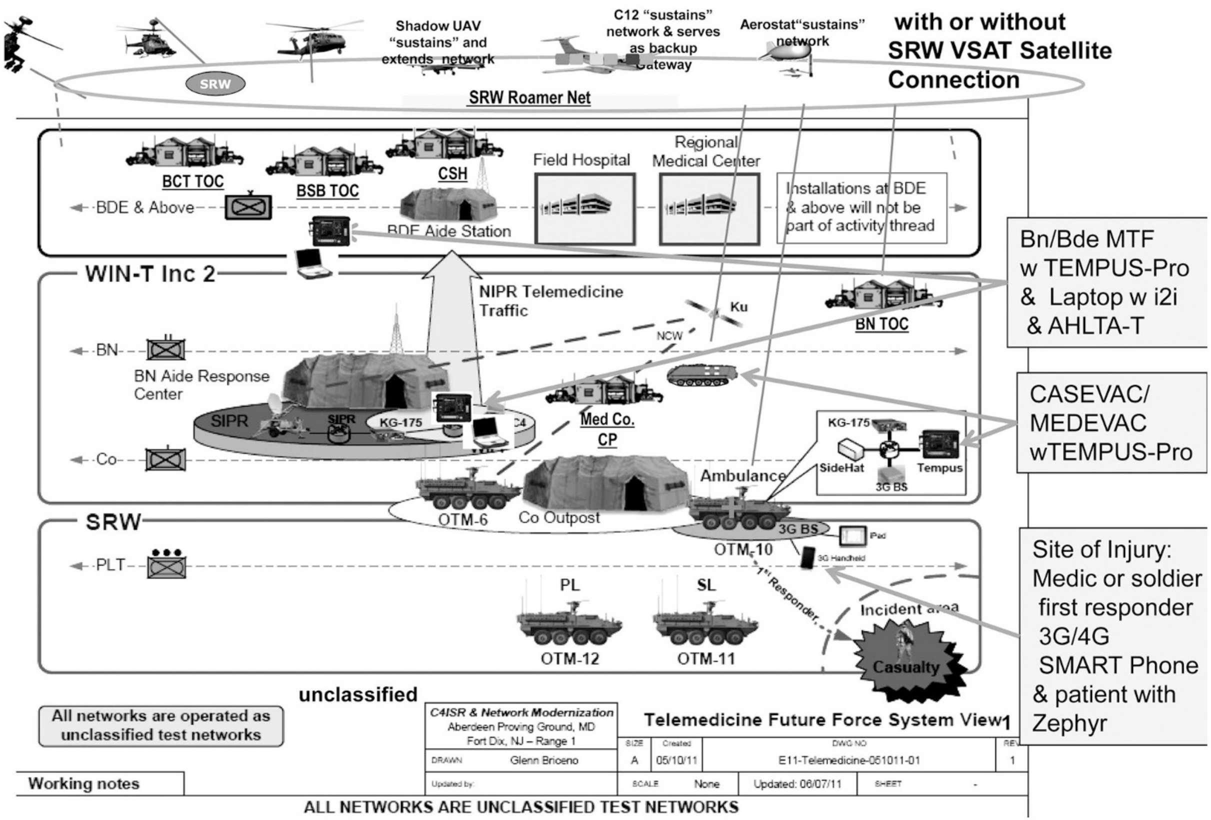

Fig. 1.9 Concept of medical information flow from the point of injury to combat support hospital and CONUS facilities. This highlights a test utilizing 3G/4G smart phone communications of physiological status information from first responders, collected through a monitoring system (e.g., Tempus-Pro), and transmitted into the AHLTA-T medical record. Illustration courtesy of Dave Williams/Carl Manemeit

TATRC has been involved in this HIT research domain from its inception, dealing with early issues around transferring and archiving radiographs. A wide range of Congressional Special Interest (CSI) projects, Army Advances in Advanced Medical Technology Initiative (AAMTI) projects, and Small Business Innovative Research (SBIR) programs explored many aspects of electronic data acquisition, analysis, archiving, retrieval, display, and dissemination and utilization for modeling and simulation, data extraction, and visualization. Annual TATRC investments in health IT research over 5 years (through FY10) averaged $25 M per year.

The TATRC Common Development Environment (CDE) was a laboratory tool developed exclusively with Army funding for early-stage research support to developers responsible for integrating with and building military health systems (Fig. 1.10). The CDE supported Composite Health Care System (CHCS), AHLTA, Nationwide Health information network (NwHIN), and mobile health systems development. It provides a state-of-the-art software development and testing platform for numerous platforms (Windows, Unix, Red Hat Linux, and VMS) easily accessible to MHS, Industry, and Academia. The CDE allowed for easy collaboration on early-stage Research and Development (R&D) efforts. The Patient Ancillary Web Services (PAWS) platform for network-enabled patient data retrieval was developed by TATRC using the CDE. The CDE was also used to demonstrate the ability to transfer a standardized medical record between VA, DoD, and Kaiser Permanente Health Care through the standard Federal health Architecture (FHA) gateway and agency adapter. This was a first step in the development of the Presidentially mandated Virtual Lifetime Electronic Record ("VLER 1a") (Fig. 1.11). A new version of the CDE with expanded capabilities such as a mobile Health test component, the Early-Stage Platform, has gained support through the JPC1 program.

The new JPC1 effort (FY10+) was directed by a technical workgroup composed of DoD Chief Information Officers and Chief Medical Information Officers (CIOs and CMIOs), led by Steve Steffensen. This group was responsible for technical leadership of the JPC1 research in Health Information Technology (HIT), including the open EHR, m-Health/telemedicine, and medical device interoperability. The initial assessment of the workgroup concluded that early-stage HIT R&D was fragmented and unpredictable. It was based on programs whose funding was irregular and unpredictable (e.g., SBIR, CSI, service-funded programs) and the MHS-funded enterprise R&D projects did not fully benefit from early-stage R&D (Fig. 1.12). This resulted in significant amounts of directed R&D funding spent without linkage to military needs and without a strategy to use the research findings to evolve health IT knowledge; major investments in health IT were made within the TMA program offices without the benefit of early-stage R&D funding to explore options and mitigate programmatic risk. In FY10, the group established a plan to execute early-stage R&D that supported Health Affairs (HA)/TMA and military services. This was coordinated across organizations and funding sources, mitigated risk for enterprise systems, identified technology insertion and/or transition process, provided an environment for collaboration of health IT R&D stakeholders, aligned with the MHS Information Management/Information Technology (IM/IT) strategic

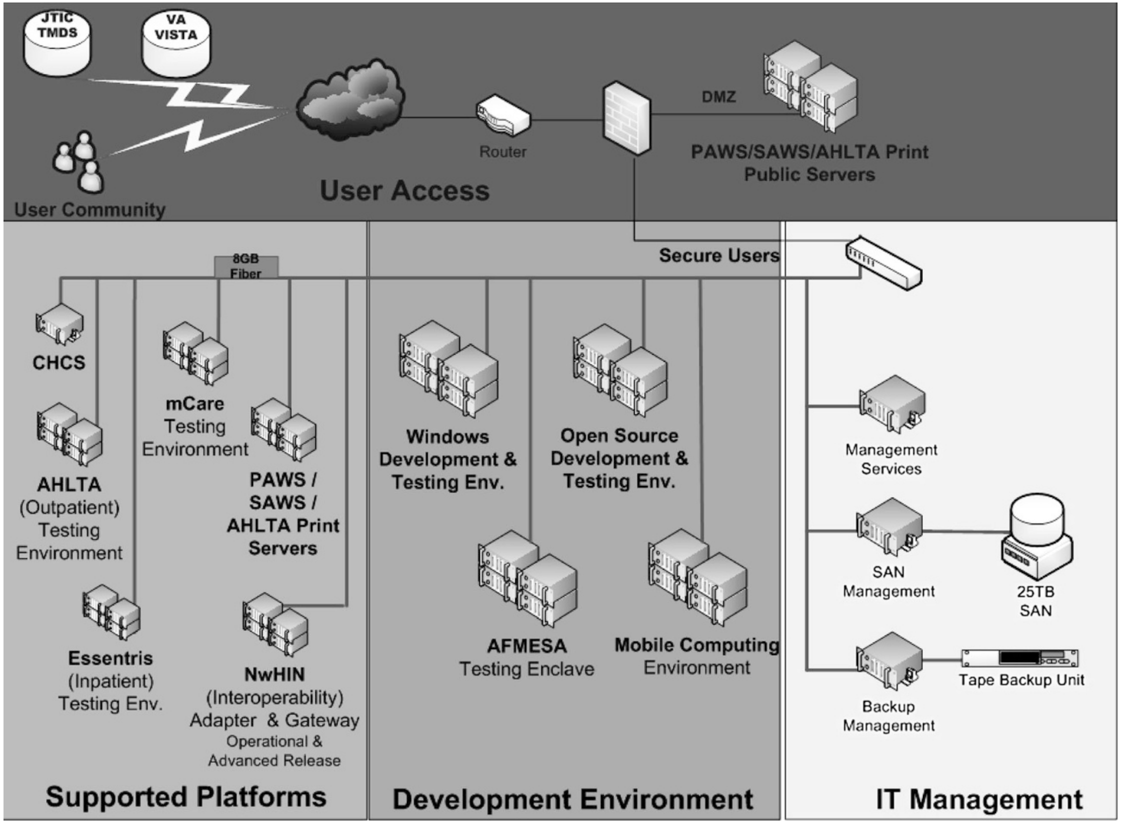

Fig. 1.10 Organization of the TATRC ESP (formerly the Common Development Environment, CDE), showing platforms currently supported, the user environment interfaces, and supporting IT structure. This capability has been vital to development of programs such as PAWS and provided the test environment for VLER1a and other interagency experiments in Health IT. Illustration courtesy of Tom Bigott

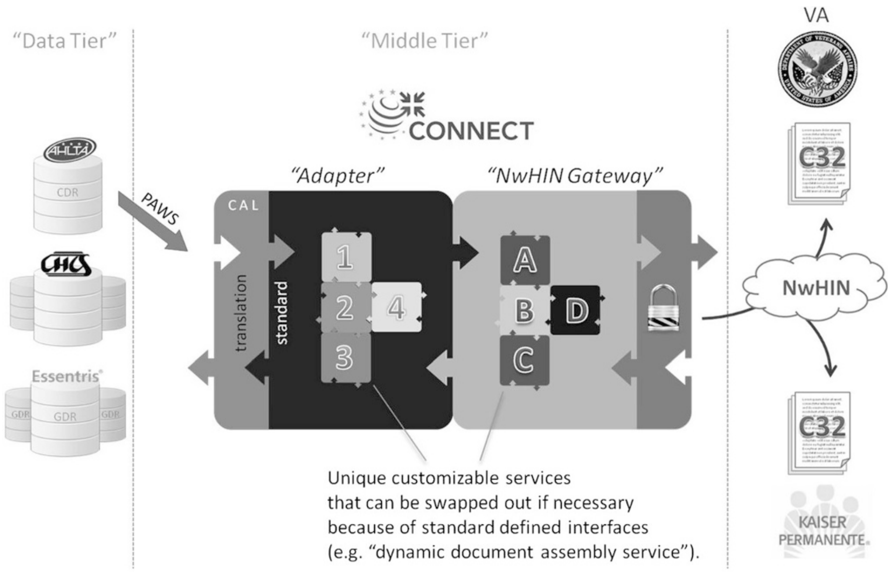

Fig. 1.11 Flow of information in the Nationwide Health Information Network (NwHIN) for an initial Virtual Lifetime Electronic Record (VLER) demonstration project that successfully transferred a C32 medical record between agencies. This was demonstrated using the TATRC ESP capability

plan, and strengthened the technical infrastructure for collaborative R&D. Four projects were supported with the limited first year (FY10) funding to address data analysis, display, and utilization research gaps (described below).

There was no tool in the MHS that has made aggregated health data in the EHR accessible and useful to clinicians, administrators, or researchers. This gap was addressed in studies with Clinical Looking Glass, a commercial application that allows clinicians and researchers to build dynamic complex patient cohorts at their desktops for real-time statistical analysis of health outcomes. Originally developed and demonstrated at Montefiore Hospital in New York, NY, this tool provided meaningful access to clinical data for quality improvement, IRB-approved research, and clinical education [53]. The application, adapted to the MHS, was used to support more than 20 studies and was piloted in the Walter Reed National Military Medical Center (WRNMMC) Medical Home. It enabled quality assurance (QA) and comparative effectiveness studies, the publication of research studies, and the validation of research findings in military facilities with military data. This showed value in improving quality of care for chronic care patients, such as those with diabetes, kidney failure, and heart disease, and in reducing costs associated with readmissions.

Predictive modeling tools are critical to the care and long-term outcomes of injured warfighters. The Knowledge Management Repository (KMR) developed by CAPT Emory Fry at the Naval health Research center in San Diego, California,

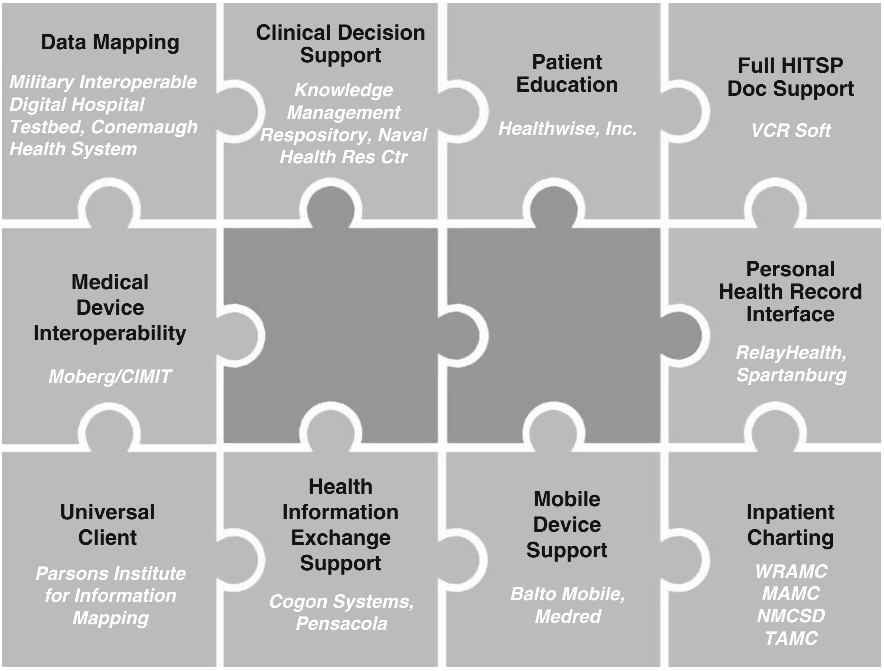

Fig. 1.12 Interrelationship of projects representing early development of Military Health System health IT research that have been supported through Congressional special interest funding prior to the establishment of the new JPC1 core-funded research program. Future SOA services can be developed to support additional use cases for both the NHIN and the MHS. These components plug into the standard-based enterprise service bus to rapidly provide new functionality

and related distributed decision support system were novel tools to predict increased workload from mental health issues for returning warfighters. This was based on a scalable predictive model using statistical and machine learning algorithms to develop models for resource planning and capacity management of posttraumatic stress disorder (PTSD) patients in a resource-constrained environment. The infrastructure and tools can be configured and generalized for other resource planning requirements. The goal was to embed these models in a new health care planning tool designed to investigate how population characteristics and operational data influence demand forecasting under a variety of risk profiles, as defined in the TATRC-sponsored 2007 Morningside Initiative [14]. The KMR platform was adopted as the reference middle tier for the Nationwide Health Information Network (NwHIN) to provide its services across diverse infrastructures. The open source code developed was contributed to the Federal Health Architecture (FHA) as a reference analytic platform for use by the CONNECT community. This DoD contribution by Dr. Steve Steffensen and CAPT Emory Fry to enable the conversion of agency-specific data elements to standardized sharable information in the NwHIN was recognized with a ComputerWorld Honors Award in 2008.

A variety of visual dashboards and heads-up displays of patient conditions were explored in DoD research including systems for the Operating Room of the Future pioneered by investigators in the CIMIT program (Boston, Massachusetts) and by the Parsons Institute for Information Mapping (PIIM) (New York, New York). The PIIM prototyping continued with JPC1 funding in support of the Program Executive Office (PEO)-Health IT at TRICARE Management Activity (TMA), to design a dashboard using standardized visual styles (e.g., typography, graphics, iconography) to support views for various personnel in the clinical environment. The PIIM Visualization Toolkit (PVT) streamlined engineering of prototypes while retaining a deployment-ready technology stack. This effort used the Patient Ancillary Web Services (PAWS) platform for network-enabled, patient data retrieval and compliments these technologies with PIIM-developed write-back functionalities. PIIM also investigated innovative ways to visualize patient health information and patient health histories, creating "Intelligent Iconography" from existing health information to provide snapshot visualizations of patient health and histories. This method would compress complex and historical patient and public health data into single, comprehensive, and portable visualizations. PIIM's work showed that better visual displays, more intuitive user experiences, and easy-to-use tools are crucial to a successful EMR.

Various graphical user interfaces (GUIs) were developed as workarounds for providers to obtain information from different systems, connecting the Veterans Health Information Systems and Technology Architecture (Vista) and DoD's Composite Health Care System (CHCS) information into a common view. Janus was an example GUI application developed to provide a common view for dual beneficiaries. This effort started under the leadership of Stan Saiki in 2003 as a demonstration at Tripler Army Medical Center (TAMC), where VA and DoD services are collocated and dual beneficiaries can access both services. Providers needed a way to access information from two completely different health information systems, including pharmacy orders and laboratory results; a bi-directional pharmacy ordering interface was also developed as a first of its kind in the US. In 2009, JANUS was upgraded to include the ability to share the different systems' PACS images. The changeover between different systems was an even larger issue for the transfer of records from the DoD to the VA (or the Indian Health Service) when soldiers left the service. TATRC explored numerous projects in the transfer of information between medical organizations through bidirection health information exchange networks (BHIE), as well as developing an immediate fix to the problem of medical record transfers between DoD and VA polytrauma centers when this became an urgent issue in OIF (personal communication, MAJ Frank Portals, 2007).

The CIMIT program involving a consortium of the major medical research organizations in Boston, Massachusetts, supported the Medical Device "Plug-and-Play" Interoperability program led by Julian Goldman. This program grew with direct TATRC support and also secured a National Institute of Biomedical Imaging and Bioengineering (NIBIB) multi-institutional quantum grant focused on full integration of medical equipment and electronic health record systems into smart networks through the Integrated Clinical Environment (ICE) framework. This included development of software tools and simulation environments to accelerate innovation in clinical applications and produce error-resistant medical device systems (i.e., ICE-compliant equipment for military and civilian care). The requirements for this research were outlined in national strategy meetings [54].

In March of 2008, Seong Ki Mun and COL Hon Pak convened the National Forum on the Future of Defense Health Information Systems (National Forum) at Georgetown University to address major themes in the development and implementation of the longitudinal health record (LHR) [23]. This TATRC-sponsored forum brought together experts from government, industry, and academia to focus on longitudinal health records, systems architecture, knowledge management and discovery, and interoperability. The results from this forum were published in a special supplement to the Journal of Military Medicine. A summary of the high-level recommendations from the forum is summarized in Table 1.4.

Current JPC1 investment in development of recommendations for a framework for aspects of the electronic health record research effort includes policy (RAND), data standards and interoperability approaches (MITRE), and modeling and simulation efforts (SEI). These collaborative efforts with Federally Funded Research and Development Centers (FFRDCs) were intended to address strategic focus areas as a foundational activity. The developmental activities over a decade were largely shaped by rapidly changing external forces such as deployment experiences (e.g., 1990/1991 Gulf War mystery illnesses and medical documentation), technology advances, and funding opportunities (Fig. 1.1). JPC1-funded experiments target near-term MHS research concerns in identity and registry management to test policies and procedures regarding who can access medical data and how to regulate it. Agile development processes were a key aspect of testing the roadmap. This called for clinical user community involvement throughout the development (i.e., Pasteur model of use-inspired research), instead of "waterfall" development

Table 1.4 Key recommendations from the National Forum [23]

• Development of a joint VA-DOD strategic roadmap and vision of the LHR
• Development of a joint VA-DOD strategic roadmap and vision of personalized medicine.
• Development of a joint VA-DOD enterprise data management strategy and common information model
• Creation of a federal AHLTA-VistA development environment to foster innovation and closer collaboration
• Creation of a joint DOD-VA health services research center with integrated data warehouse, dedicated support, and specialized services for internal and external research
• Development of a joint DOD-VA strategy for leading the national health information exchange
• Development of a clear Personal Health Record strategy as part of the LHR
• Implementation of service-oriented architecture for the LHR
• Leverage industry best practices on rapid software development, testing, and deployment
• Development of a clinical informatics workforce and organizational framework
• Development of an approach to defining requirements, preparing requests for proposals, and awarding contracts that create fairness and foster competition

involving the intended user only at the beginning and end of the project. Foundational researches on policy, interoperability, data standards, and clinical modeling and simulation were keys to solving problems with patient safety, medical care efficiency and cost reduction, and rapid implementation of innovation. This research effort was intended to develop concepts and products up to the level of "enterprise capable" and then hand them off to operator testing and development of "enterprise ready" systems by the TMA/DHIMS (Table 1.5).

Future interoperability for the EHR, as well as other cloud computing and database applications, will depend on interoperability standards and semantic web technologies. TATRC supported foundational work in this area, especially through the CIMIT program and Massachusetts General Hospital for the creation of national and international standards led by Julian Goldman [54] and the semantic web technologies in the TexShield program led by Parsa Mirhaji [55]. The Morningside Initiative outlined an approach to manage collaborative knowledge sharing with clinical decision support to include genomics and to involve public and private sector participation [14].

1.6.4 Computational Biology and Predictive Models

In 1999, Harold Varmus received recommendations on information science and technology from an expert panel whose observations were also relevant to other federal agencies: "Increasingly, researchers spend less time in their "wet labs" gathering data and more time on computation. As a consequence, more researchers find themselves working in teams to harness the new technologies. A broad segment of the biomedical research community perceives a shortfall of suitably educated people who are competent to support those teams. . . What is needed is a higher level of competence in mathematics and computer science among biologists themselves" [56]. The DoD also recognized this critical need [57]. For at least a decade, Jaques Reifman led computational biology in DoD medical research, with a mandate to collaboratively develop these capabilities in military medicine. As one example, he promoted the use of DoD high-performance computing resources to solve medical research problems in biological defense. With support of a multiyear grant from a DoD High-Performance Computing office, his team developed and implemented 14 software applications for research on diagnostic assays and to identify drug and vaccine candidates (Fig. 1.13). These tools provided significant advantages in time and efficiency for military lab researchers with virtual screening for drug discovery, potentially reducing months or years of work to days. One of the most widely used applications, the Docking-based Virtual Screening (DOVIS) software, developed for screening of small molecule drug candidates based on receptor-ligand interactions, was downloaded by over 1000 users in the research community [58]. Another application, the Protein Structure Prediction Pipeline (PSPP), provided a tool that could be used on any high-performance system to conduct sophisticated analysis of three-dimensional protein structures from known sequences, including rapid

Table 1.5 Significant accomplishments of the Joint Technical Coordinating Group 1 (JTCG1)

Developed a next-generation interactive, full body-trauma casualty system that behaves autonomously to provide realistic training for medics, reducing the instructor training load and adaptable to changing training requirements. The COMETS manikin was developed at Massachusetts General Hospital/CIMIT and is commercially available as CAESAR (CAE Ltd.)
Created a common development environment for state-of-the-art software development and testing, supporting CHCS, AHLTA, NwHIN, and mobile health systems development by the MHS, Industry, and Academia. This research capability permitted development of the Patient Ancillary Web Services (PAWS) platform for network-enabled patient data retrieval and was used to demonstrate the ability to transfer a standardized medical record between agencies through the standard Federal health Architecture (FHA) gateway and agency adapter
Developed mCare to connect injured warriors with their case workers at the Community-Based Warrior Transition Units (CBTWUs) utilizing the soldiers' personal cell phones for bi-directional HIPAA-compliant messaging managed by a central, secure web portal and system. The system has already been used to send over 138,000 secure messages reminding patients of appointments and disseminate administrative, health, and wellness information and assisting case manager information management and real-time alerts for critical issues. mCare was recognized as one of the Army's Greatest Inventions of 2010
Used the existing Army Knowledge Online secure email system to establish the teleconsultation program that answers rapid consult requests by on-call specialists in more than 19 medical and seven dental specialty services, with a total of 9285 consults to theater serving more than 2292 deployed provider users since its inception, and with referrals resulting in prevention of unnecessary evacuations and facilitation of appropriate evacuations. AKO teleconsultation services were extended to all NATO forces in 2008
Piloted the commercially available Clinical Looking Glass software at WRNMMC Medical Home to increase access to clinical data for quality assurance and comparative effectiveness studies, the publication of research studies, and the validation of research findings in military facilities with military data. The application, adapted to the MHS, has been used to support more than 20 studies and is currently being piloted in the WRNMMC Medical Home and shows value in improving quality of care for chronic care patients and in reducing costs associated with readmissions
Identified and advanced a technology solution (the TEMPUS Pro) for point of injury medical monitoring and casualty data acquisition through downselection of candidate technologies in a JCTD and in subsequent field studies and network integration experiments, resulting in early technology adoption by SOCOM and the Marine Corps Warfighter Laboratory. The system generates a digital TCCC record of patient encounters, provides voice, physiological data, and still photo or video transmission for telementoring, and transmits medical information over secure tactical networks from forward deployed medics to supporting medical treatment facilities and ultimately to update AHLTA and Theater Medical Data Store
Developed family of high-performance computing software applications for research on diagnostic assays and to identify drug and vaccine candidates, providing significant advantages in time and efficiency for military lab researchers with virtual screening for drug discovery, potentially reducing months or years of work to days. Some of these applications have been downloaded by over 1000 users in the biodefense research community
Developed tools for DoD pharmacovigilance in collaboration with the FDA to use powerful data mining programs to identify drug associations with adverse events in the clinical data repository. These products are used by the newly established DoD Pharmacovigilance Center

examination of thousands of models assembled using energy functions and other rules [59]. Such tools complement traditional laboratory methods to determine protein structures, providing a major advance in the ability to analyze potential binding partners and active sites and to support efficient in silico drug screening.

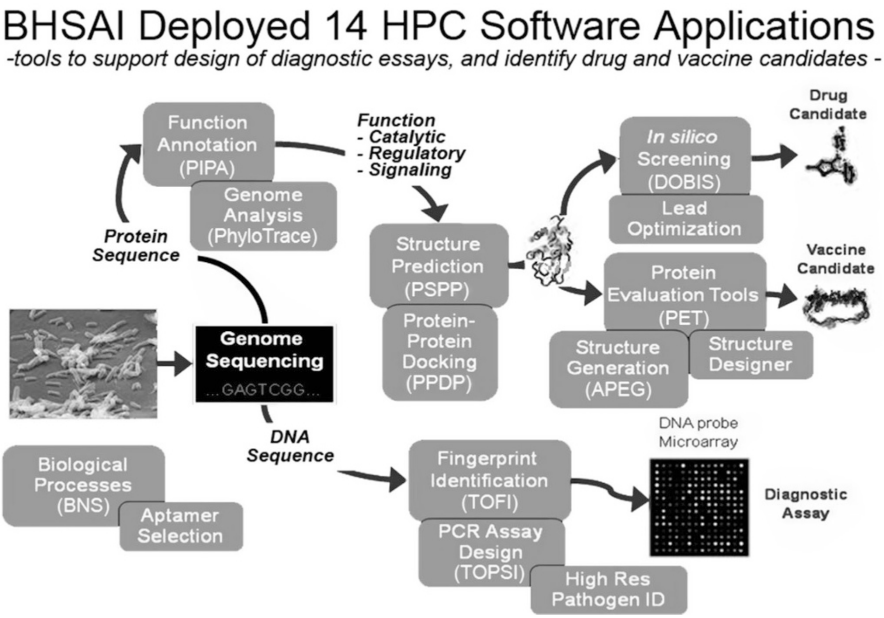

Fig. 1.13 Schema of biospecimen analyses addressed by high-performance computing applications developed by the BHSAI. The development of these software applications came about from intramural laboratory collaborations and was funded through a competitive grant from the DoD High-Performance Computing Modernization Program. Illustration courtesy of Dr. Jaques Reifman

The work accomplished under this initiative addressed research gaps identified in the 2001 TATRC strategic plan for biomedical informatics, including all of the near and mid-term gaps [15]. The longer-term strategic objective expanded the effort to a sophisticated information management system that could process an unknown sample [60], match its characteristics to related known chemical or biological threats, and produce relevant threat management recommendations (drawing on the worldwide database of relevant existing studies).

Jaques Reifman's Biotechnology High-Performance Computing Software Applications Institute (BHSAI) had a large network of collaborations, including tri-service research laboratory participation. In addition to the development of analytical tools, the BHSAI modeled biological processes from algorithms and tools that advance physiological monitoring systems [61] to human sleep physiology studies [62] and thermal strain predictions [63] to in silico replication of metabolic networks for drug discovery (that help reduce reliance on animal testing) [64]. Systems biology problems were addressed in blood coagulation [65], traumatic brain injury, PTSD, and glucose regulation for closed loop system regulation [66, 67]. A key limitation to advances in the widespread application of such computational methodologies is often the limited access to datasets. New data sharing requirements pioneered by the NIH and new concepts of immediate data sharing to accelerate scientific discovery [68] help to remedy this problem.

Sensor data fusion with a physiological underpinning has been a key shortfall in soldier monitoring for more than 30 years since this was seriously considered. The personal status monitor described in Heinlein's Starship Troopers was the conception for a system that would permit a commander to have full intelligence on the performance readiness status of troops and would help medics and support casualty evacuation [16, 69–71] (Fig. 1.14). Many versions of monitoring devices have been proposed including the Army's WPSM (Fred Hegge, personal notebooks), NASA's Lifeguard [72], and a wide variety of commercial products. The challenge has not been in the engineering of smaller measurement devices, but in the management of the information from a minimal combination of sensors to predict outcomes of interest (performance impairment from fatigue, life-threatening hemorrhage, likelihood of death, impending environmental injury, etc.). Commanders and medics may not find raw physiological data of use with elevated heart rate signifying activation for combat or life-threatening hemorrhage. Meaningful interpretation of the signals are not trivial problems, yet have been largely overlooked except for a few efforts such as those of Reed Hoyt at USARIEM [73–75] and Jaques Reifman at the BHSAI [76, 77]. True decision support systems are necessary when there are billions of

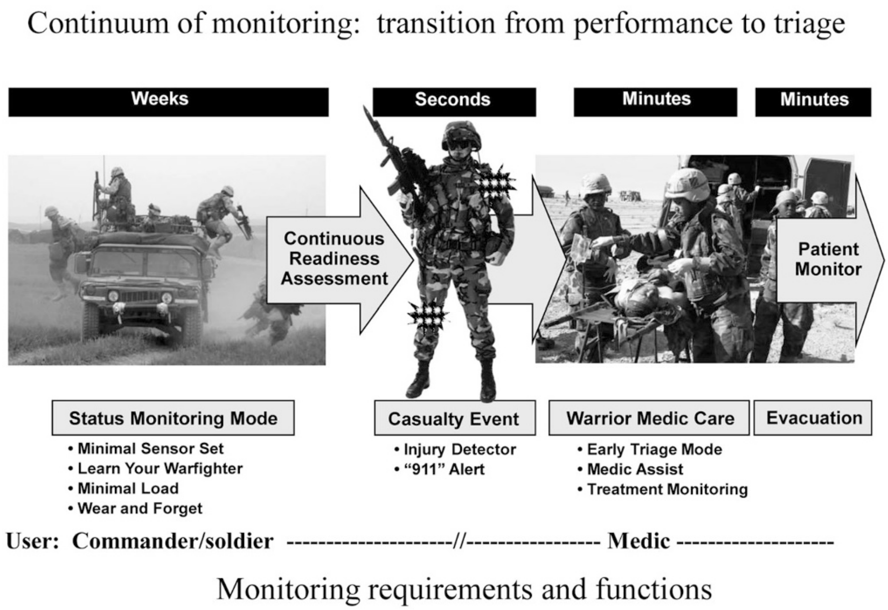

Fig. 1.14 The Warfighter Physiological Monitoring (WPSM) concept, first articulated by Dr. Fred Hegge in 1996, includes wear and forget sensors that provide intelligence to commanders on soldier readiness and convert to a medical monitoring mode when a casualty event is detected and through medical evacuation. Development of computational biology models to accomplish sensor data fusion and create actionable (useful and reliable) information has been the rate limiting step in advancing WPSM decision support systems. Illustration reconfigured from Friedl, NATO technical workshop HFM-151, 2007

options, and informatics and computing technologies now make this feasible in complex integrative multi-scale models.

Even before decision support tools are validated and approved for medical interventions, these models can provide near-term casualty monitoring benefits and could be integrated into the same systems that medics will bring to the casualty starting at the point of injury. Andy Reisner developed an automatic processing system for assessment of injury severity using full-automated diagnostic algorithms that analyze vital signs patterns of trauma patients transported by Boston Medflight using an innovative plug-and-play computing platform [78]. The longer-term goal from the 2001 strategic planning meeting included developing a computer-based medic aid for triage of unforeseen injury conditions. This would run on a smart phone type of device or perhaps on a medic-borne medical monitoring device also connected into the health IT network such as experiments that were conducted in the JCTD.

Closed loop regulation of glucose and volume control in casualties was a near-term goal of the same modeling efforts, with national research efforts and standards driven by Robert Vigersky and David Klonoff [79, 80]. A productive Army collaboration produced a universal data-driven model to predict subcutaneous glucose concentrations, made possible by the availability of important patient datasets to develop and test this model [66]. High reliability predictive algorithms will be useful for interpretation of new continuous glucose monitoring technologies as well as in closed loop systems including the military trauma pod of the future.

The medical community has an important role in developing models of human tolerances and damage risk criteria for military materiel developers to be able to conduct their human factors and safety planning for new materiel and systems, including personal protective equipment and survivable systems [81] (Fig. 1.15). Comprehensive biomedical models can provide developers with an in silico prototyping capability that would be especially powerful when combined with any of the many other military human systems models [82]. This supported the Secretary of Defense's objective to increase use of prototypes to ensure that programs are ready for subsequent phases of development (Robert Gates, testimony before the SASC, January 27, 2009). Such virtual prototyping tools of human limits assist materiel and combat developers in considering human health and performance from the very start of a new program. Physiological models for health hazards assessment and prototyping of better soldier protection have been conducted for more than a decade for problems such as blast, auditory, and inhalation toxicology exposure limits [83–85]. However, these individual hazard assessment models have never been combined in militarily realistic comprehensive models (e.g., effects of blast exposure combined with inhalation of fire gases, or brain injury outcomes affected by head impact in combination with metabolic status, hemorrhage, psychological trauma, etc.). The complexity of such modeling tends to be underappreciated and requires considerably more experimental data input, collaboratively developed with the modelers, than a single animal or cadaver experiment. For example, a significant modeling effort on blunt impact risk could provide important insights into effective lighter weight body armor. Developing a new scientifically based evaluation system

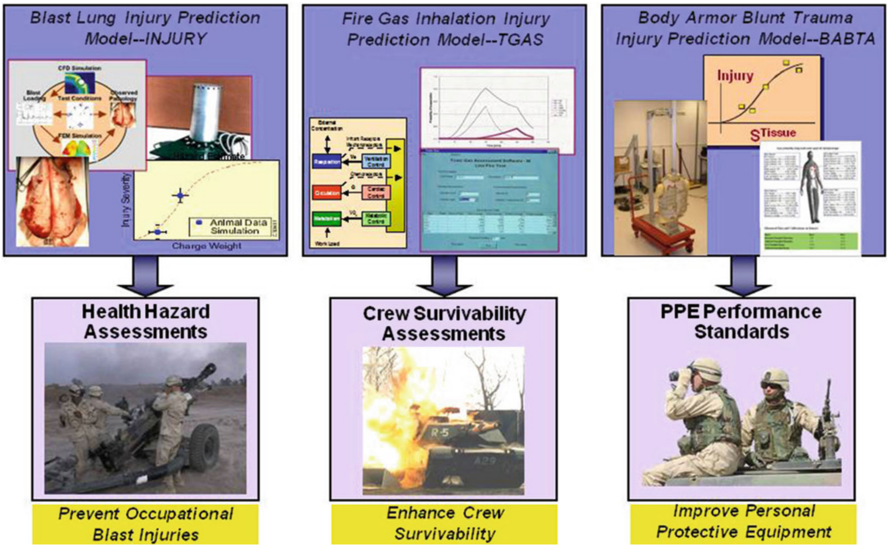

Fig. 1.15 Damage Risk Criteria have been developed from physiological models such as the three examples illustrated in this figure. Each of these computational models, critically important to nonmedical materiel developers, was developed by Jaycor/L-3, San Diego, Californa. Illustration courtesy of Mike Leggieri

that could replace an antiquated clay deformation test involved finite elements modeling (FEM) of pig and human torsos based on CT images, a series of animal blunt trauma tests with CT images, measurement of chest wall motions and lung pressures, and pathology data, and then scaling of the human FEM to simulate equated frontal and side human subject impacts [86]. An Army and Marine Corps collaboration was initiated to develop a comprehensive model of load carriage for mission planners and materiel developers. This was supported by JPC1, in close coordination with JPC5 (Military Operational Medicine).

1.6.5 Knowledge Engineering

To make the growing body of biological data available as an organizational memory, there is a critical need to develop methods of knowledge conservation (storage and curation), retrieval, and analysis. There is extraordinary power that comes from accessing the growing electronic database cloud and this information will become increasingly accessible through the development of semantic systems tools. The possibilities for global medical disease monitoring using information already available in disparate databases were epitomized by the work of Rita Colwell in the prediction of cholera outbreaks 6 months in advance of the event based on oceanographic and meterological data [87]. Useful information can be derived from widely disparate sources of data. Even massive multiplayer games have been used to gain new insights into human behavior during a lethal epidemic, as was observed by the peculiar rush into danger by players during the inadvertent spread of an infection in the Worlds of Warcraft game [88]. Medical situational awareness systems were explored by TATRC and the potential was illustrated by early experiments by the ISIS Center (Georgetown University) with Project Argus. The Argus experiment explored early detection of biothreat events based on automatic detection of combinations indicators of social disruption, such as changes in the use of medical services and other public behaviors in a region [89]. Patterns and content of communications between soldiers may identify behavioral health issues or provide automatic indicators of unit cohesion and stress. Automatic knowledge generation through algorithms, models, fuzzy logic associations, and tools such as those produced by Google were important for useful conversion of data to information and knowledge. In an earlier collaboration with TATRC and the 1994 Defense Women's Health Research Program, Fred Hegge conceived the Army Medical Knowledge Engineering System (AMKES) for automated access to medical knowledge based on storage of information "nuggets" (generic knowledge objects, GEKOs), each containing values for rule-based utilization [90]. The application to providing women with current breast cancer information was recognized with a Computerworld Award. The shortfall in this system was the labor-intensive creation of the structured knowledge elements. The DoD pharmacovigilance system led by Colonel Trinka Coster in collaboration with the FDA has explored the use of powerful data mining programs to identify drug associations with adverse events in the clinical data repository [91]. Current efforts with specific registries such as the Joint Theater Trauma Registry have provided immediate value to the current deployment combat casualty care. Using this database, many trauma care issues were identified and addressed through education or changes in clinical care, including the development of 27 evidence-based clinical practice guidelines. The damage control resuscitation guideline was associated with mortality decrease in massively transfused from 32 to 21% [92]. The JTAPIC system combined medical casualty data with information about personal protective equipment, vehicles, and contextual information such as tactical situations to produce vital intelligence changing threats to soldiers and effectiveness of protective equipment against those threats [20]. The WDMET database was an early attempt at such a database. Started late in the Vietnam War to retrospectively investigate effectiveness of protective equipment, the investigators lacked modern computational tools that would have made this feasible and essential to agility in modern warfare [93].

Emerging technologies such as semantic web technology will make these fixed data element standalone registries unnecessary with push-of-the-button access to all relevant data derived from existing medical records and other data systems. Semantic web technology development was a critical investment area for JPC1. An effective EHR eliminates the need for any future "registries," any of which could be established with a few key strokes. Ultimately, modeling depends on data. For researchers developing new knowledge, national data sharing is critical to the speediest advance of knowledge creation. New breakthrough data sharing models such as the national Alzheimer's Disease Neuroimaging Initiative (ADNI) have already produced unanticipated benefits across the board in accelerating interpretation and utilization of this important information to advance industry and academic efforts in disease monitoring and drug development [68]. Semantic tools to facilitate sharing of important data from the massive military investment in TBI and PTSD research are urgently needed.

1.7 Conclusions

The soft boundaries for JPC1 research were drawn around the main objective of the research. Within the military medical funding domain, if the intent is to develop information technologies or test the efficacy of the tools in their applications, it fell to JPC1. If the primary intent of the research was to solve a key question in prevention, diagnosis, treatment, or rehabilitation of dengue infection, PTSD, TBI, or vision loss, it would probably fall to other specialty programs such as JPC2 (Infectious disease research), JPC5 (Operational medicine research), JPC6 (Combat casualty care), or JPC8 (rehabilitative medicine). The boundaries were very soft for JPC1 because of the cross-cutting nature of information science. It would be reasonable to expect the JPC1 to subsume the majority of the military medical research investment within a few years, as the research world transform science to information science. At that point, it would represent a common basis for convergence science and would no longer need a distinct specialty program, with full integration in all the other research areas. At its start, the new JPC1 program was composed of relatively small demonstration projects that were beginning to form the interconnections of larger consortia and comprehensive efforts spanning disciplines and organizational boundaries. The JPC1 program should lead the convergence of information science, cyber infrastructure, and biomedical research in military medicine with multi-scale multimodal multisite science.

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This manuscript was originally prepared, reviewed, and cleared for a special issue of Military Medicine in 2012 that never materialized. KEF wrote the paper when he was the Chair of the Joint Programmatic Committee (JPC1) and Director of the Telemedicine and Advanced Technology Research Center (TATRC); TBT and SS also worked for TATRC and they contributed important concepts captured herein and in the initially funded JPC1 program in their capacities as JPC1 subgroup Chairs for the Med Sim Technical Working Group and Health IT Technical Working Group, respectively.

Disclaimer The opinions and assertions in the paper are those of the authors and do not constitute an official position or view of the Department of the Army.

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Chapter 2
Technological Options for Enhancing ADU's Sustainability: Solar PV and Insulation

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2.1 Introduction

During the economical recession of 2008/2009, Portland saw housing and rent prices go down (pretty much like any other major city in the United States), and by that time, nothing was said about housing or affordability problems. After the recession, nonetheless, the city experienced a strong growth—people from all over the country and really from all over the world started moving to the city, attracted by its features, including the weather, abundant nature, social diversity, and strong economy. The fact that the economy was in a good shape again and that thousands of people were moving here, made the real estate and rent market to suffer from a supply shortage, thus leading prices to skyrocket—ultimately creating what is now being called the housing affordability crisis (see [1, 2]). To make matters worse, Portland is expected to grow even more in the next decades, and that brings concerns to the population as well as to policy-makers around infrastructure capabilities, among which housing stands out as one of the biggest challenges. According to [3], the metro-area population could receive up to 725,000 new residents in the next 20 years, and [4] states that the city of Portland alone might experience an increase of 56–74% of its households by the year of 2035. All of the studies and reports that deal with the expected growth in the City of Roses highlight housing as the biggest issue to be tackled. As aforementioned, as of now, Portland already is facing severe housing affordability problems, and once population starts to grow even further, the building of new housing does not seem to keep up with the demand. On [5], the journalist raises the question whether the city is/will be prepared to accommodate all of its new residents in the next few years.

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Another critical issue that surges when analyzing the "population boom" Portland is and will continue to face in the future is the sustainability. The city has always been a pioneer in being aware and planning ahead for dealing with sustainability issues, and it has been successful by creating, promoting, and implementing action plans aiming to reduce carbon emissions and deal with climate change. However, such a drastic change in population density will likely pose serious threats to those initiatives and also bring new challenges to be tackled by the city. The very fact that more people are coming to the city already implies more carbon emissions. On top of that, structural improvements (such as construction work, increase in the city basic systems, etc.) will also contribute negatively to the city ecological footprint. Therefore, one can ask a very basic yet difficult question: How will the city of Portland continue to be sustainability-oriented while undergoing such a fast-paced and large-scale change in population?

Specifically with regards to the housing problem, some solutions are being considered by policy-makers, one of which is called "urban infill"—the act of taking advantage of "idle" spaces in pre-existing neighborhoods to create new dwellings. One of the most popular and consolidated forms of urban infill is the Accessory Dwelling Unit (ADU), a concept that consists of building small dwellings in the lot of a single-family house, whether an attached ADU (in the basement, for instance), or a detached ADU, on the backyard, or over the garage, for example. By disseminating ADUs, the city would be able to absorb some of the new population while avoiding some of the structural changes (one these new residents would live in already existing neighborhoods, with all the infrastructure in place already). Another advantage of ADUs would be the fact that the owners would have an extra income source, by renting out the ADU (or the contrary, moving to the ADU and renting out the main house). One of the biggest challenges in the promotion of ADUs and other alternative housing options comes from the market. Although the trend shows that a very considerable share of the people who are looking for housing needs small dwellings (two or three persons), builders are still building almost only big houses (that could accommodate five to six persons. Of course, those bigger houses are more expensive, thus helping the housing market to become even more subject to inflation. This mismatch between demand and supply is not easy to deal with. It requires a large dose of studying and understanding, in order to put the right market transformation policies in place—and even if one can successfully implement those, the results might take time to come.

Technologies have been, throughout history, solving humanity's problems and enhancing our quality of life. Specifically within the realm of sustainability, there is a myriad of new technologies trying to decrease the side effects (social and environmental) of economical progress, ensuring that humans are able to explore our natural resources and organize ourselves as societies in a healthy and balanced fashion, for generations to come. Our objective with this study is to understand how technologies can help tackle the housing problem while still maintain or even increasing the sustainability of new housing options. Specifically concerning ADUs, we ask: How does technology help ADUs to become more sustainable, so that it can be used as a tool to mitigate the Portland's population boom without hindering the city's sustainability?

2.2 Electricity and Sustainability

Sustainability, while extremely popular and widely used, is not a very well understood concept. Most of the people would think of it just as everything related to conserving the nature and/or Earth's natural resources. In reality, the concept is much broader and thorough than that, and it is very important to be aware of the depth of this concept. According to the United Nations Environment Programme [6], a sustainable business or system is the one which aligns and takes care of, at the same time and to the same extent, environmental, social, and economical aspects—therein the term "triple bottom line" was coined (organizations should start to value the social and environmental spheres as much as they do with the economical one).

Although technological developments can and are used to create betterments in those three spheres, we are focusing more on the environmental part, especially on the relationship between energy (generation and usage) and environmental effects.

Energy is one of the most precious resources humanity makes use of, and the energy sector is probably the most complex and costly industrial sector of all. The energy industry is also the one that raises the biggest questions and concerns when it comes to sustainability and environmental issues. Analyzing the carbon emission, the production of electricity and heat is responsible for the biggest share, 25% (according to the Environmental Protection Agency [7]), and all the other sectors (agriculture, transportation, buildings, industry, other energy) involve energy and electricity usage. Therefore, should anyone want to tackle the environmental issues, it should primarily start with electricity production and usage.

When it comes to residential electricity usage, one can also notice that the heating and cooling are responsible for the biggest share. According to the U.S. Energy Information System website [8], in spite of not representing the absolute majority of energy consumption in residences anymore, space heating and cooling still stands out as the primary source of electricity use in American homes.

Obviously, by analyzing these data, one can conclude that there is a very intimate relationship between electricity generation and carbon emissions. Similarly, there is also a very intimate relationship between electricity usage and carbon emissions. The biggest villains in those relationships are dirty nonrenewable energy sources (such as coal) and space heating and cooling needs.

Portland, the state of Oregon, and the whole Pacific Northwest region have a different reality regarding electricity when it comes to generation. Due to its immense availability of water, the region produces most of its electricity through hydroelectric power plants (which can be very polemic and damaging during its construction and implementation but are surely one of the cheapest and cleanest energy sources once the facilities are in place). Due to its lower price and high availability, electricity in the region tends to be more widely used than in other regions in the country (applications such as cooking, water heating, clothes drying, and others could be and are fed by other energy types such as natural gas in other regions). Regardless of how clean the electricity in the region is, energy-efficiency initiatives are still valid and should be taken seriously. Moreover, the fact that the region produces clean energy does not necessarily mean that the region consumes this clean energy.

Transporting the discussion to the technology world and also trying to tie it up with Accessory Dwelling Units, there are two technologies that address those two villains: Solar PV systems and insulation materials.

Solar PV systems produce clean and renewable electricity from the sun so that consumers need less (or do not need at all) electricity coming from standard sources. Insulation materials applied on walls, ceilings, doors, and windows reduce the heat loss from the inside environment to the outside environment, thus reducing significantly the need to use electricity for space heating and cooling. We now proceed to discuss and analyze those technologies, their technical specifications and functioning methods, their applicability to ADUs, and how they can turn ADU's into an even more sustainable solution to deal with the emerging problems Portland is facing and will continue to face in the future.

2.3 Solar PV

This section aims to inform the reader about basic characteristics and the applicability of Solar PV systems to ADUs. As subsections, there is a general overview, solar PV application and benefits, solar PV market status and outlook, installation cost of Solar PV, solar PV's contribution to sustainability, how solar PV enhances ADUs sustainability, and solar PV on ADUs cases.

2.3.1 General Overview

2.3.1.1 Configuration of a Solar PV System

A Solar PV system generally consists of a solar panel connecting series of photovoltaic (solar) cells that generates electricity. The solar cells are typically made of silicon and convert the energy of sunlight directly into direct current (DC) electricity by means of photovoltaic effect. Then, there is an inverter used to convert the DC into AC power for providing electricity to the appliances' usage [9].

Depending on the connectivity with grid, the Solar PV may encompass Utility-connected (grid-tied) and Utility-independent (off-grid) systems. For the grid-tied installation, the home can draw energy from the grid when it needs more or can inject it into electrical grid when producing excess electricity. This is called "Net Metering." The off-grid system is often used in remote location or away from the utility [9].

2.3.1.2 Solar PV Technology

A variety of materials and technology involve the manufacturing of PV panels. The most common type of PV panel is crystalline. This technology has been around for about 50 years and is considered highly reliable. They may be huge, expensive, and require more labor to install, but they are often the best choice for residential solar system. The other example is thin film modules. This is considered inexpensive, due to less active material required to function. However, their less efficiency and long-term durability is often questionable [9].

2.3.1.3 Solar PV Application and Benefits

The Solar PV technology has been widely utilized in many industry/sectors. Some of the examples are listed below [10]:

- For Cottages and Residences: This is considered as an economical option for remote cottages and residences. In addition, Solar PV provides the autonomous source of electricity during a power outage.
- For Mobile and Recreational Application: The Recreational vehicles, boats, and expeditions can benefit from using portable PV to recharge batteries.
- For Agriculture: The Solar PV system can be used to pump water for livestock, plants, or humans or can be used to power remote electric fences on farms.
- For other applications: PV cells can be used in calculators, watches, telecommunications equipment, highway construction sighs, parking lights, and so forth.

The Solar PV can offer many advantages/benefits as follows [11, 12]:

- Renewable and available everywhere in the world
- Safe, clean, and quiet to operate
- Highly reliable and virtually no maintenance
- Cost-effective in remote areas and for many residential and commercial applications
- Flexible and can be expanded at any time to meet the electrical needs
- Increased autonomy and independence from the grid or backup during outages

2.3.1.4 Solar PV Market Status and Outlook

The international Energy Agency (IEA) reported that the cumulative PV capacity grew at 49% on average since 2003. In 2013, about 37 GW of new PV capacity was installed in about 30 countries. This brings total global capacity to over 135 GW [13]. Solar Power Europe reported that 40 GW of PV systems were installed globally in 2014, resulting in 178 GW of total solar power installed in the world [14]. The above market information shows global cumulative PV capacity has been growing.

The GTM Research reported that U.S. solar market had a strong first quarter (1306 MWdc of installation) in 2015. The residential market grew about 11% over Q4 2014 and seems continuously increasing over the past 5 years [15].

For Oregon, 8 MW of solar electric capacity has been installed in 2014, where 7 MW were residential and 2 MW were commercial. There is tremendous increase of solar installation in 2015 so far, reaching more than 35 MWdc [16].

2.3.1.5 Installation Cost of Solar PV

There are many factors influencing the total cost of installing solar system, which may include size of system, system location, system efficiency, solar panel cost, system design, cost of installations, permitting and application, and others. Generally, large and efficient system, cheaper panel cost, and sunnier climate, all will contribute to the cost reduction for the PV system. As an example, the residential solar system installed in Oregon costs about $4.73 per watt in 2013. From 2011 to 2013, the average cost of small solar system has dropped from $6.63 per watt to $4.69 per watt. The equipment costs of the solar system dropped more sharply than that of nonequipment cost [17].

In addition to the cost factors mentioned above, the total solar PV system cost can be reduced by means of incentives and tax credit. As an example, Oregon Green Energy Guide provides the following calculation process. It assumed that solar system costs about $4–$6 per watt, or $12,000–$15,000 for a 3000 watt residential installation [18].

2.3.2 Solar PV's Contribution to Sustainability

2.3.2.1 Solar PV Energy Cost Saving

For Energy efficiency measure, an ADU can be embedded with well-insulated walls, which will reduce the house's electricity usage. A new solar PV system can remove the house from the electricity grid. As a demonstrated cottage ADU project showed that a Net-Zero-Energy ADU will create energy savings that impact the local economy. For instance, if households save $25 in energy cost each month, construction of 4000 ADUs could add additional $1.8 million on purchasing local goods and services each year [19].

Another example of typical southwest house shows that a roof top solar system has a long expected lifetime exceeding 25 years, because there are no moving parts. For the inverters, there is a replacement cost after 12 years. Other assumptions include no other maintenance cost, due to the 25-year warranty. Based on these conditions and assumptions, their calculation results shows that the estimated monthly saving is $84/month average over 25 years. The breakeven point will occur at 147 months (12.3 years) [20].

2.3.2.2 Solar PV and CO_2 Emission

Among all the cumulative technology contributions to power sector emission reductions, Solar PV accounts for 20%, which is the largest contributor compared to STE (Solar Thermal Energy) 9% and Hydro 6%. The PV systems installed by the end of 2013 generated 160TWH/year of clean electricity and thus avoided about 140 million tons of CO_2 per year (MtCO_2/year) [21]. This shows how PV can contribute to the reduction of CO_2 emission.

According to The National Renewable Energy Laboratory, a DOE national laboratory, it was reported that "An average U.S. household uses 830 kWh of electricity per month. On average, producing 1000 kWh of electricity with solar power reduces emissions by nearly 8 pounds of sulfur dioxide, 5 pounds of nitrogen oxides, and more than 1,400 pounds of carbon dioxide" [22].This demonstrates that the Solar PV system not only can contribute to the reduction of CO_2, but also reduce emission of other Greenhouse Gas Emissions.

2.3.3 *How Solar PV Enhances ADU's Sustainability*

2.3.3.1 Energy Cost Saving

Based on a quotation from Solar City at Oct 29th 2015, the ADU will need 3.0 kW DC system generated by 8 panels installed facing southwest to maximize production for fulfilling 800 kWh/month. Battery is optional, if smart-grid can be applied for selling energy to the grid. In addition, it cannot be off grid as it needs a little electricity to start up the system. The calculation is shown below [23]:

Total cost = \$10 k
After tax rebates = \$7.5 k
Estimated payback time = 10 years
From then on = at least 20 years of free electricity

All maintenance and repair work is included.

This brief example demonstrates the solar energy cost-saving and the extent of facilitating the sustainable benefits.

2.3.3.2 Net Metering Benefit

According to U.S. Energy Information Administration, the response to "How much electricity does an American home use?" is "In 2014, the average annual electricity consumption for a U.S. residential utility customer was 10,932 kilowatt-hours (kWh), an average of 911 kWh per month. Louisiana had the highest annual consumption at 15,497 kWh per residential customer, and Hawaii had the lowest at 6077 kWh per residential customer" [24].

Those numbers consider the average of all American houses (most of them consume much more than an ADU). It can be assumed that an ADU would consume much less electricity than 900 kWh a month: this system would be able to make the grid independent (nearly), increasing the sustainability significantly. Moreover, if one opts for installing a battery, one would be able to sell excess energy to the grid (once the Smart Grid Applications are in place), generating another source of income.

2.3.3.3 Battery System

The solar PV systems can be installed and used with or without a battery system attached to it. The use of a battery system brings some advantages and also some disadvantages for the user.

When choosing to use it without battery, the user would still be able to “sell” its excessive electricity back to the grid. In this case, the system would work as the following: During the day, the system (depending on its capacity and the level of sunlight) will produce more electricity than the user needs. Since the system is integrated with the grid, this excessive electricity would be thrown into the grid automatically (the utility meter starts to run backward), thus “selling” energy to the utility company. During the night, the system will not produce any electricity whatsoever, and then the user will “buy back” that electricity he/she has sold throughout the day, by feeding his house with electricity directly from the grid. In the next day, the cycle starts over.

When choosing to use it with battery, the user may have the option of being completely off-grid (provided both solar PV and battery systems have the adequate capacities). In this case, the system would work as the following: During the day, the system will produce more electricity than the user needs, and this excessive electricity, instead of being thrown into the grid, will be stored in the battery system for later usage. During the night, when the PV system is totally idle, the house will use the electricity from the batterythat has been storing electricity throughout the day.

Regardless of the choice, both systems are much more sustainable than just relying on the grid as an energy source. We now present the pros and cons of a solar PV system supported by a battery system:

Pros

- Resilience: if there is a battery system in place, the house will be protected from eventual power outages. In that case, the battery would provide the electricity needed until the power is back (or it would be already providing the electricity in case it is an off-grid house)
- Economic Gain: when there is no battery in place, the user “sells” electricity to the utility company whenever the system is producing more than consuming;

therefore, the user has no control of when or how much it is selling. Conversely, if there is a battery system in place, the user might want to choose the most profitable time periods to "sell" it back to the utility company. For instance, instead of throwing it back into the grid during the morning (when the rates are lower), the user can choose to "sell" it during the peak hours (when rates are higher). Nonetheless, it is very important to notice that this economical gain would only be achieved if there are some "smart grid" applications in place (e.g., two-way communication between user and utility and real-time monitoring of energy consumption). In that case, the utility company would be able to know exactly when and how much electricity is being "sold" and then it would reimburse the user with the applicable rates on the next bill (provided, obviously, that the utility company wants to buy electricity from the user).
- More Sustainable: by having a battery system installed, the user might have the option of never using electricity from the grid, meaning being completely independent from any dirty energy source, such as coal or natural gas. In that scenario, the carbon footprint of the ADU would be even lower.

Cons

- Cost: of course, the battery system has an extra cost on top of the solar PV system, and the costs are dependent on the total storage capacity of the system (the bigger the capacity, the higher the cost). This extra cost would add more time to the payback period of the whole system.
- Engineering risk: from an engineering perspective, every system should be designed and implemented as simple as possible—the simpler the better. The more components or parts the system has, the greater the chances of failures and breakdowns. By adding the battery, the user is adding a whole new system that should have a maintenance plan and repair work done periodically, thus making the system more complex, costly, and more prone to break.
- Start-up electricity: the solar PV system needs, every morning, a small amount of electricity to be started up, and the grid usually provides this electricity. In case of a system with battery but connected to the grid, it would not be a problem. However, if the system is off-grid, some issues might occur. In that case, the battery should always reserve some electricity for the next day, or else the system will not work—that, in turn, limits to some degree the way the user can operate the system.

2.3.3.4 Solar PV Key Technical Considerations

Preinstallation Considerations [25]

- Suitability: (Is your site suitable for a solar array?)

Ideally, the site for a Solar PV system should receive sufficient direct sunlight. It is necessary to check if there are shading issues caused by adjoining buildings, trees, or any other obstructions.

- Space: (Do you have enough space for home solar panels?)

The requirement for electricity will mostly determine the size of the Solar PV panels. For the relatively smaller size of ADU, it seems to be more important to check if there is sufficient square footage for installing the required Solar PV panel.

- Regulation: (Are there any state or municipal installation restrictions?)

Considering possible unique regulations for renewable energy systems in different areas, it seems critical to check the local administration for obtaining approval or permits before starting the solar project.

- Electricity Requirements: (How much of your energy needs can you meet with solar energy?)

Given the average home uses about 900 kWh monthly, the relatively smaller ADU will consume less electricity. Therefore, how much energy needs will be fulfilled through solar energy needs to be estimated accordingly.

System Design Considerations [26]

- Area needed:

There are some general guidelines. For example, unobstructed roof space needed approximately equals to 20–25% of total house square footage. For 100 square feet of space, 1 kW of solar module is needed.

- Roof Orientation:

Generally, the most beneficial orientation for solar panels is to the southwest. It may still necessary to check the ideal angle of inclination in the project area. For instance, the optimal tilt of a PV in the Pacific Northwest equals the latitude minus about 15° for maximum output [27].

- Shading Problems:

Although the major shading issues need to be considered in advance, the possible obstacles from the house itself need to be reaffirmed. Especially, during the time period from 9 am to 6 pm, the shading problem ought to be minimized to the least extent.

Technology Selection Considerations [28]:

- PV system types:

The PV system can be connected to the utility grid, known as utility-connected or grid-connected. In addition to be used for electrical appliances, the surplus power can be pushed back to the utility grid. This is sometimes utilized as a virtual battery bank for the house. If PV system does not connect to the utility grid, this Net metering feature will not work.

- Battery back-up:

The PV system without battery is considered as the simplest and least expensive configuration. However, an electricity outage will shut down every electrical device. Conversely, the battery back-up will help maintain power to the electrical equipment during power outrage. Nevertheless, batteries tend to make PV system less efficient, add installation, maintenance, and replacement cost.

2.3.3.5 Solar PV on ADUs: Cases

1. Grant Sawyer [29]
   - Basic information:
     - Types: Detached, new construction
     - Year of completion: 2014
     - Total Square Footage: 728
     - Total Cost: $187,000
     - Cost/Square Foot: $256
   - The benefit/features of Solar PV application:
     - The owner's comments: "The 5.2 KW solar PV system, which essentially will result in a net zero energy home."
2. Jill's ADU: A Home of Her Own [30]
   - Basic Information:
     - Types: Type: detached garage conversion
     - Year of completion: 2011
     - Total Square Footage: 420
     - Total Cost: unknown
   - The benefits/feature of Solar PV application:
     - There are grid-tied solar panels installed on the ADU, which cover electricity for the lights, appliances, and heating.
     - For the past 2 years, this ADU has produced more electricity than it had used over the course of the year. Therefore, this ADU may be regarded as net zero electricity building.

3. Rose House [31]
   - Basic Information:
     - Types: Detached, new construction.
     - Year of completion: 2004
     - Total Square Footage: 800
     - Total cost: unknown
   - The benefit/features of Solar PV application:
     - The goal of this demonstration project is to utilize Solar PV panels so as to generate more electricity than it uses.
     - This ADU is the first house in Portland to receive Earth Advantage's Platinum Certification.
4. Karen Chapple [32]
   - Basic Information:
     - Types: Backyard cottage
     - Year of completion: 2011
     - Total Cost: $100,000
     - Rent per month: $1200
   - The benefit/features of Solar PV application:
     - By using a new solar photovoltaic system, this removes the cottage and the main house from the electricity grid.
     - With other sustainability design features such as well-insulated walls, this ADU has demonstrated a Net-Zero-Energy Affordable unit located in west Berkley, CA.

Implications/Summary of Case Studies

- These case studies demonstrate the application of Solar PV on some specific ADUs including Net Zero Energy demonstration projects and homeowner's new construction projects.
- One of the cases shows that the Solar PV has played an important role in enhancing the sustainability of the ADU toward obtaining the green building certification.
- Cost benefits have been also justified from the ADU built for rental purposes.

2.4 Insulation

This section aims to inform the reader about basic characteristics and the applicability of Insulation systems to ADUs. As subsections, there is a general overview, energy efficiency, and sustainability considerations and applicability to ADUs.

2.4.1 General Overview

Insulation is the technique that tries to make it difficult for heat to travel through different spaces/environments. Taking this notion to buildings, insulating walls, ceiling, doors, and windows is an attempt to make the building more independent from the outside temperature – ultimately producing thermal comfort using much less energy. In order to understand how insulation works, it is necessary to understand how heat flows.

Heat always tends to move from warmer areas to colder areas, that is the reason why, during the winter, the warmth inside buildings will try to "escape" to the outside environment through walls, doors, and windows. Conversely, during the summer, the warmth outside buildings will try to "invade" the inside environment through walls, doors, and windows. There are three ways this heal flow or heat transfer occurs: conduction; convection; radiation.

Conduction happens when heat is transferred by direct molecular contact, and it takes place in solids, liquids, and gases. For example, if one sticks a metal piece inside a hot liquid, one will notice the heat being transferred from the liquid to the metal piece. In buildings, it can take place when the heater is turned on and warms up the walls, which, by conduction, will transfer the heat to the outside of the building.

Convection is a process that occurs in both liquids and gases. When a gas is heated and gets in contact with cooler air, the air is heated and becomes less dense, hence being forced upward and being replaced by cooler air, which in turn also gets heated up and starts the process all over again. This process creates a cycle, or a constant air flow that gradually "steals" heat from the original material. The same is observed in liquids. When heating up a bowl of water, for instance, the water that is at the bottom of the bowl (and therefore closer to the heat source) is hotter than the water at the surface. Gradually, by convection, a constant flow of water takes place and eventually the system gets into equilibrium (all the water gets to the same temperature). In buildings, heat transfer by convection can occur through wall or roof cavities.

Radiation is the third and final method of heat transfer. Radiation occurs when infrared energy is transferred from a hot surface to a cold surface through air or vacuum. The radiant energy has the special characteristic of not heating anything unless it hits a material that can absorb the energy. For example, the radiant energy from the sun travels millions of miles through the space (vacuum) without heating anything, only to be absorbed by people/buildings/etc. when it gets to the Earth.

In buildings, it can occur when the energy from the sun is absorbed by construction materials (e.g., walls) and then it is emitted from those materials into the building.

Every material allows, to some degree, heat to flow through it. However, some materials are much more resistant to heat flow—and those are known as insulators. Fiber glass, rock wool, and slag wool are examples of insulators.

In order to block (or minimize considerably) the heat flow between spaces, insulators should be applied, and those insulators should be able to minimize all three forms of heat transfer. In order to minimize conduction, the material should be consisted of several thin layers interconnected or discontinuous fibers (it should have a small amount of solid in relation to void)—therefore creating barriers for heat to be conducted. In order to minimize convection, the material should have small void pockets or air pockets, limiting the ability of air to move through it, consequently limiting convection. In order to minimize radiation, the material should have a "low emissivity" surface, meaning the material should absorb the less radiation possible (reflecting instead of absorbing)—the less radiation absorbed, the less radiation emitted afterward.

There are some metrics that assess the thermal behaviors of materials and combination of materials, and those metrics are used to inform how good an insulator is in blocking heat transfer. The most important of those metrics is the thermal resistance (R value), which measures a material's ability to resist the transfer of heat. An *R*-value is a unit of thermal resistance for a particular material or assembly of materials (such as an insulation panel). The *R*-value depends on a solid material's resistance to conductive heat transfer. For loose or porous material, the *R*-value accounts for convective and radiant heat transfer through the material. However, it does not account for the radiant or convective properties of the material's surface, which may be an important factor for some applications.

R is expressed as the thickness of the material normalized to the thermal conductivity. The unit thermal conductance of a material is the reciprocal of the unit thermal resistance. This can also be called the unit surface conductance. The higher the value of *R*, the better the building insulation's theoretical effectiveness.

There is also the thermal conductivity, aka *K* value (which is used to calculate the *R* value) and the thermal transmittance, aka *U* value. The *U*-factor, or *U*-value, is the overall heat transfer coefficient that describes how well a building element conducts heat or the rate of transfer of heat (in watts) through one square meter of a structure divided by the difference in temperature across the structure. The elements are commonly assemblies of many layers of components such as those that make up walls, floors, roofs, etc. It measures the rate of heat transfer through a building element over a given area under standardized conditions. This means that the higher the *U* value, the worse the thermal performance of the building envelope. A low *U* value usually indicates high levels of insulation. They are useful as it is a way of predicting the composite behavior of an entire building element rather than relying on the properties of individual materials.

Among the various insulation materials available in the market, the air- or gas-filled panels (for walls) and air- or gas-filled windows and doors stand out as the best performing products.

Gas-filled or air-filled panels are considered an advanced insulation technology, and these products consist of two external aluminum foils/ polymer laminates and five internal specially formulated, aluminum-metalized firms. The material has support from the U.S. Department of Energy, and researchers at the Lawrence Berkeley National Laboratory made efforts to develop GFP thermal insulation technology to help apply the technology into several different industries, such as packaging, transportation, aerospace, and building. The polymer chamber is designed in such a way that it is surrounded by a sealed barrier and filled with air or a low conductivity gas. The technology is also used with double- and triple-paned gas filled windows. The application of GFP started in the military (tents) to minimize the energy use and has won the award of the insulation product of the year at the 2011 Global Insulation Conference and also succeeded in tests with ASTM (American Society for Testing and Material). Some of the advantages of GFP are (see [33])

- High thermal performance. It has ability to reach a range of *R*-values using different gases and keep *R*-value over a wide range of temperature.
- Sound. It has excellent sound transmission class ratings if we compare with other industry standard insulation products.
- Compact. It has flexibility for ease of storage and transport and it is almost flat.
- Adaptable. It can be found in different thicknesses and lengths depending on the application.
- Moisture resistant. Retards moisture and resists mold growth.
- Clean and safe.
- Mold Resistant—it doesn't have cellulose or any products that would serve as food for mold.
- Lightweight—it is easy to transport and install.
- Meets LEED and other Green Building Program Requirements.

By having a good insulation system installed, the building will experience less heat transfer (the inside environment will be more independent and less impacted from the outside environment). Therefore, less energy will have to be applied to the inside environment to turn it into a comfortable habitable space.

The costs for vinyl-insulated windows and doors with air- or gas-filled technologies can vary considerably depending on the quality of finishing and materials involved, but we can get a notion of it by considering prices from the best selling products in big retail stores, such as Lowe's and Home Depot

Vinyl-Insulated windows (with argon between glass layers for more energy savings):

Size: 36 × 36	Price: $ 117.00 (for Living room)
Size: 24 × 36	Price: $ 107.00 (for bedroom)
Size: 24 × 24	Price: $ 97.00 (for restroom or kitchen)

Vinyl-Insulated doors: prices range from $230.00 to $310.00 each.

The costs for insulation materials for walls and roofs can also vary considerably, depending on how effective (*R*-value) and easy to install they are. As with the windows and doors, we can take as an example the best selling products in big retail stores.

Insulation panels (air-filled panels with *R*-value = 14):

- \$10.85 each panel (24 inches wide × 10 feet long)

2.4.2 Energy Efficiency and Sustainability Considerations

Heating and cooling represent the biggest sources of energy consumption in residential settings, and the insulation materials—provided they are well installed and with high quality—can help in saving energy form in those activities. The goal of insulation systems is to make the internal temperature of a house the most independent possible from the outside temperature—i.e., it tries to keep the house cooler during warm periods and tries to keep the house warmer in colder periods. Therefore, it allows users to decrease its energy consumption significantly. According to [34], the share of energy used inside any kind of building that is affected by its building envelope (insulation system) is 20–60%.

The Environment Protection Agency (EPA) estimates that, by installing insulation systems, end-users can reduce their heating and cooling energy consumption by 15–20% and that would represent an overall energy cost savings of about 11%. Moreover, the North American Insulation Manufacturers Association (NAIMA) presents really interesting facts about the usage of insulation materials/systems:

- Insulation reduces average home heating and cooling costs by around 20%.
- Insulation currently in place in U.S. buildings reduces the amount of carbon dioxide by 780 million tons each year.
- This is the equivalent of over 150 coal-fired power plants.
- This is the equivalent to the electricity use of over 90 million homes for 1 year.
- This is the equivalent to the output of 1.645 billion barrels of oil or the energy equivalent of 5.5 barrels of oil per American.
- For every Btu consumed in the production of insulation, 12 Btus are saved each year by the use of insulation.
- For every pound of carbon dioxide emitted in the production of insulation, 330 pounds of carbon dioxide are avoided by the use of insulation.5.
- Insulation saves over 600 times more energy each year than all of the compact fluorescent lights (CFLs), Energy Star Appliances, and Energy Star windows combined.

2.4.3 Applicability to ADU's

As any other energy-efficiency measure, utilizing insulation materials/systems will not only contribute by making your house more sustainable (decreasing the energy use), but will also bring economic value.

Many building-material manufacturers spend less of their revenue on research than other sectors of the economy, because of the commodity-based nature of building materials and products, the long cycle to change to new technology, and relatively low profit margins.

The insulation market is highly mature, and global material suppliers are actively increasing sales in developing markets. While the majority of suppliers are responsible and provide accurate information about product performance, including building application advantages and disadvantages, there are some instances of overly assertive companies marketing materials that may not be in the best interest of consumers [35].

The applicability of these materials to ADUs is by no means a problem, since the construction techniques utilized in ADUs are the same as in any other dwelling unit—in fact, ADUs are only different from "regular" houses due to its size. Nonetheless, some questions and concerns may arise when one thinks of how to promote these materials and make sure they are used in new ADU's constructions.

2.4.3.1 Technical and Performance

A plan and appropriate design for meeting ADUs needs of all economic segments of the community. Technical assistance regarding the sustainable and specification of insulation materials needs to encourage ADU's development and improve their affordability [9]. The performance of insulation types may vary according to types of applications, climates, and the aging of materials. For example, when loose-fill fiberglass insulation is applied to thick depths in attics in very cold climates, a thermal siphon effect will occur and performance will be reduced. Some time ago, this phenomenon was documented and the resultant test and rating adjusted to reflect the true performance of the product in that application. Similarly, newly formed foam insulations usually have reduced performance after several years due to air diffusing into cell structures that reduce blowing agent concentrations. New test protocols have been developed that provide an aged rating that will reflect the true life of the product's performance [35]. The ADU insulation materials should meet and comply with the Energy Star specification through Earth Advantage to help ensure that the builder is using the best available framing, sealing, and insulation practices. The builder must build to Energy Star standards and is contractually obligated to use the "Thermal Bypass Checklist' and relevant 'Critical Details" and "Tech Tips" from the Northwest Energy Star website. To help ensure good water protection and air-sealing quality, some developers are using SIGA Majvest weather-resistive barrier and Wigluv sheathing tape. Some of them are getting technical drop-in visits from the Energy Trust subcontractor outreach specialist. They use the Earth Advantage to conduct a blower-door test to check the air pressure and to help identify any sealing gaps [34].

2.4.3.2 Policy and Regulation

Although regulations regarding ADUs are being addressed in some cities, there is still a lack of solutions that please both homeowners and renters alike, causing tension and debate when creating regulations. For example, quality-of-life concerns like noise can be regulated through various policies and better enforcement techniques. Right policies and regulations offer a way to balance neighborhood fears with the needs of other community members who appreciate the opportunities that ADUs provide [36]. In all instances where access to existing ceiling, floor, or exterior wall space is possible without demolition, insulation shall be installed. New windows or doors must meet current Residential Code requirements for energy conservation. Existing double-glazed windows or storm windows placed over existing single glazed windows are acceptable.

2.4.3.3 Public and Personal

The use of insulation materials can help reduce air emissions, while at the same time, promote sustainable development and economic growth, and improve public health. Due to the availability of a clear specification of specific cost-effective energy-saving technologies like insulation technologies, the building industry and its suppliers can bridge the gaps between environmental protection, public health, economic advantages, and community development [37]. Construction costs, design constraints, and financing are the most common barriers to ADU development. So, people need less expensive and sustainable ADUs insulation materials [38]. ADU developers are mostly homeowners with personal financial and family goals. Curiously, these owners do not always choose to maximize their returns in a business sense. Some charge little or no rent even when market rents are easily obtainable; some spend significantly on green features such as insulations; some house older relatives.

Going beyond the general needs and concerns involving ADUs and insulation materials, it is also possible to identify some specific issues that derive from that relation. The two most important issues are

- Accelerated heat loss rate
- Moisture trap

Heat loss (or heat transfer), as aforementioned, is likely to occur in any dwelling unit—and that is precisely what the insulation materials work to avoid or minimize. However, in the specific case of an ADU, due to its small area (compared to a "standard" house), that heat transfer process can occur much faster. If one thinks of a standard single family house, around 2000sq feet, with a particular insulation system installed, it would take a certain amount of heat transfer (and therefore a certain amount of time) in order for the external environment to exert influence over the inside environment. Conversely, if one thinks of an ADU, around 500sq feet, with the same insulation system installed, it would take a proportionally smaller amount of heat transfer (and therefore a proportionally smaller amount of time) in order for the same effect to take place. Hence, we could conclude that ADUs, by their very nature, are more vulnerable to heat transfer than a larger dwelling unit. The implications of such a situation are twofold.

Firstly, there are some technical considerations to be made. As the ADU is more prone to lose/gain heat from outside, factors such as the insulation design and most importantly the insulation materials installation become extremely crucial toward an effective insulation performance. If the installation of the insulation panels is not adequately done, the energy-efficiency benefits expected from the system might be in serious jeopardy.

Secondly, there are behavior considerations to be made. After properly designing and installing the insulation system, the builder can instruct and inform the end-user how to take advantage of it—i.e., how to make sure to achieve the energy-efficiency benefits by "using" the ADU according to the design. Among those instructions there might be some points such as how to deal with the windows and doors—when and for how long should the user open them and in which cases should the user not open them at all. If, for one reason or another, the user completely disregards these instructions and keeps carelessly leaving doors and windows open, heat transfer will occur and certainly will hamper all the potential energy-efficiency benefits the user would expect to achieve from the insulation system. Of course, both of these factors (proper design and installation and proper use of the dwelling unit) are applicable, valid, and important to any building or housing option. Nonetheless, due to the "accelerated heat loss rate" of an ADU, in those specific cases, these factors come to play an even more important role.

The second issue is related to moisture trap [35]. Insulation materials are designed in such a way as to prevent heat from being transferred (they work as a heat barrier), but they can also (depending on a number of factors) be acting as a vapor barrier, hindering water vapor from getting in or going out of the inside environment. When that happens, the vapor ends up by condensing and the moisture (water) gets trapped either inside the house or inside the walls or ceiling. The consequences of moisture being trapped inside the house is the growing and proliferation of fungi (mold), which can lead to serious health problems to the ADU inhabitants. The consequences of moisture being trapped inside walls and ceiling is also the growing and proliferation of mold, potentially bringing health issues as well as deteriorating and rotting the ADU structure (OSB and framing).

In order to avoid these consequences, builders must be aware of them (first of all) and also must be cautious and diligent enough to choose the right insulation materials for each case. Local climate conditions should always be taken into account. For instance, for a very humid region, rigid panels and most of the insulation foams would not be recommended, as they would be more prone to act as vapor barriers in those places. Conversely, dry and hot regions would not experience this problem to the same degree. Also, regardless of the local climate, there are some insulation materials that contain special treatments, conferring to them antifungal properties, such as the air-/gas-filled panels presented earlier in this section—and those should always be preferred. Another critical consideration to make when trying to avoid mold problems in the insulation system is the thickness of the panels. Even though common knowledge points out that “the more insulation the better,” the insulation system must be thought of and must be properly calculated. Should the panel’s thickness be more than a certain level (depending on the house structure and climate conditions), the system will create an even bigger vapor barrier, moisture will be trapped inside walls and ceilings, worsening the consequences described above. Hence, the design of any given insulation system is critical to its success. According to [48, page 14], “modern insulated walls, roofs and floors can lead to moisture damage because there is less energy loss to evaporate moisture. Furthermore, thermal bridges, improper design and assembly can result in condensation within structures, so building envelopes need to be designed to avoid this problem”.

2.5 Implications and Suggestions

The systems/products analyzed in the prior sections (solar PV and insulation materials) are technically applicable to accessory dwelling units and can potentially bring significant sustainability advantages to owners. Provided their economical feasibility is also proven, it is possible to project some implications and suggestions about the usage and promotion of these systems/products, whether considering ADU owners, builders or policy-makers. The following list summarizes those points:

Owners

- In the first place, they should be conscious of their responsibility when deciding to build a new dwelling. They should be aware of all impacts such a decision has (environmentally wise) and should try to minimize those impacts, during the construction and most importantly during the usage of the dwelling.
- They should favor those builders who value and promote green solutions and products/systems.
- They should also be aware of the fact that, even though those systems might seem more expensive upfront, they will be paid off by the benefits they bring in the longer term.

Builders

- They have to be aware that consumers care about sustainability more and more; therefore, they should promote those systems and incentivize consumers to use it.
- They should educate themselves and their employees on sustainability materials and technologies, in order to make better use of it.

- By associating the image of ADUs and sustainable housing options, people will start to expect ADUs to be as sustainable as possible, forcing other builders to act toward it—congruence between society's perception of an organization's behavior and society's expectations of an organization's behavior.

Policy-Makers

- Policy-makers have to acknowledge that technology has an important impact on sustainability and on solving society's problem; therefore, more public policies should be devoted to develop and promote the right technologies.
- Policies promoting ADU's in general—lifting the burden from owners by decreasing or eliminating fees and lifting the burden from builders by making building codes more flexible and welcome to ADU's.
- Policies promoting technological development, aimed at manufacturers and most importantly at Universities and Research Institutes (research grants, tax instruments, joint research programs, consortia).
- Policies promoting new manufacturing processes and large-scale production (tax incentives for the whole supply-chain and to the manufacturers).
- Policies promoting the application of these systems (aimed at owners/ consumers). Tax rebates and credits when buying and applying these systems—like the one in place for solar PV.

The issues related to those technologies generate capability gaps, which in turn can be addressed by new technology characteristics or new ways of doing things (policies, for instance). For example, if insulation materials need cautious installation, builders need better expertise on that; therefore, training programs to educate professionals might be a good solution (or the development of mistake-free materials). Also, if a solar PV system needs a certain roof space to be installed, the design of ADUs should be able to accommodate that need, therefore more flexible building codes would make it easier for sustainable ADUs to be disseminated. The identification of elements in this "chain" can be made by a managerial process called technology road mapping. The International Energy Agency and the Bonneville Power Administration produce public technology roadmaps for the energy sector, and it can serve as a good basis to identify needs and action items required for the insulation and solar PV market. Specifically, these points should be addressed:

- General R&D is still highly needed for insulation [34]
- Policy-makers should set energy-efficiency goals and create a push toward the dissemination of technologies such as solar PV and high *R*-value insulation systems [34]
- Development of new materials such as aerogel and vacuum-insulated panels, also bringing the performance up and the costs down for current insulation solutions [34]
- Creation of retrofit-incentive programs in order to maximize the energy-efficiency capabilities of existing buildings and dwellings [34]

- Mistake-free insulation materials that can fit all cavities, e.g., sprayed fiber or foam [39]
- R&D is needed in order to produce solar PV systems that are more practical for installation in retrofit cases [39]
- Low-cost solar PV systems through the development of modularized system components [39]
- Building codes should start requiring solar PV systems to some extent [39]
- Development of building-integrated PV systems, such as solar shingles (R&D needed to improve efficiency, durability, cost, aesthetics, and ease of installation) [39]

2.5.1 Implication of Combing Solar PV and Insulated Material Toward Net Zero Energy Building

The Building America Program defines a net zero energy building (ZEB) generally as a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies [40]. Depending on the aspects of Zero Energy, there are some more specific classifications including Net Zero Site Energy Building, Net Zero Source Energy Building, Net Zero Energy Cost Building, and Net Zero Energy Emission Building [41]. Regardless those different variations, they all aim to reduce energy consumption, increase energy efficiency, and make use of renewable energy sources.

The Solar PV discussed in this report fits perfectly to contribute to Net Zero Energy target, in terms of utilizing the renewable energy for household usage. Among all possible renewable energies, Solar PV can be used in on-site supply option to fulfill the requirement for ZEB. From the aspect of energy efficiency, more sustainable insulated wall materials can be used for reducing energy consumption significantly. This also contributes to meet the basic requirements for Net Zero Energy Building. Therefore, combining Solar PV and Insulation material technology can enhance the sustainability of the ADU by increasing energy efficiency and leveraging natural solar energy.

Concerning technological development specifically, the general capability gaps for insulation materials are how to increase material performance and bring costs down at the same time and also how to create materials that are easier to install. The general capability gap for solar PV systems is how to improve panel's efficiency (currently the best panels available in the market have an efficiency around 21%) and bring costs down at the same time. Also, an important development for PV systems is how to prevent panels from heating up—when PV panels heat up, they will transfer the heat through the ceiling, hampering the efficiency of the insulation system.

In general, the actions and policies identified recommend the participation of all stakeholders and involve a number of different perspectives. And as an evidence of the space that is available for those technologies, it is relevant to mention the survey study conducted by the State of Oregon Department of Environmental Quality, which found that, in the city of Portland, only 4.1% of all ADUs make use of a solar PV system [39].

The future success of combing Solar PV and insulated material from social perspective can also be measured by the metric of how much money is being spent at this technology locality in the form of local content direct and indirect spending and investment made and what are the quantifiable benefits to the local communities from such initiatives.

2.6 Conclusion

This report had as objectives to understand how technologies can improve the sustainability of ADUs and also to suggest actions to various stakeholders in order to promote and develop these technologies. It has done so by presenting the basic characteristics of each technology being considered (solar PV and Insulation), its applicability to ADUs and the major concerns and issues to be taken into consideration, and lastly by defining implications and suggesting mostly public policies to address these issues.

The concept of sustainability, as explained earlier in this report, is thorough enough to encompass three dimensions: economical, social, and environmental, and some technologies have also the capability of influencing life in several different dimensions, including the three contained in sustainability. In general words, our analysis has touched upon those dimensions as follows:

- Economical: by making use of the proposed technologies, one is able to have economical gains, either from energy savings (and therefore lower utility bills) or even making money out of the excessive electricity produced by one's solar PV system (provided it is possible to sell it to the utility company).
- Social: by applying insulation systems, thermal comfort is more easily brought to the dwelling. On the opposite side, a well-thought design, material choice, and installation is crucial in order to avoid health issues derived from moisture and vapor trap inside the dwelling.
- Environmental: the most evident dimension in our analysis, environmental benefits are achieved by ways of using less electricity, in a more efficient fashion and from clean renewable sources, drastically reducing the carbon footprint from the dwelling.

Although the three dimensions are present, our analysis has clearly focused more on the environmental aspects of using technologies toward sustainability in ADUs. This is, in fact, the biggest limitation of this work. Future research studies could fill in this gap by deepening the investigation of how different technologies, applied to ADUs, can leverage the sustainability gains from a more economical and/or social perspectives. Such research works, combined with the present one, could help to better understand the overall framework in which Accessory Dwelling Units are inserted, ultimately aiding the stakeholders (mostly owners, builders, and government) to make more informed decisions regarding this type of housing. ADUs do, indeed, seem to be a very promising approach or solve upcoming housing issues most major cities are facing and will face (such as Portland). Nevertheless, a much broader analysis (particularly trying to anticipate all the problems a massive implementation of ADUs would bring) is required in order to arrive at a solid conclusion whether it is the best solution or not, and what is the best way to explore all of its potential.

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Chapter 3
Behind-the-Meter Energy Storage Implementation

Nicole Wehner and Tuğrul Daim

3.1 Introduction

With the growth of alternative forms of energy, and depletion of fossil fuels, energy storage will play an important part in the energy grid of the future. Mechanical forms of energy, although cheap, require specific geological features, and so increasingly electrochemical forms of energy, or batteries, are relied on. The implementation of these batteries relies on certain technological, economical, and regulatory factors. Although costs are lowering, they are still too high to have wide adoption levels at the current price level. There are opportunities to implement battery storage widely at the home level, but there is a lot of restructuring and regulations needed to jump start this process, as the traditional electrical utilities were not set up with the intention of isolated grids. Like both the solar and wind industries, market transformation will be needed to increase adoption.

Battery energy storage can be implemented at various levels of the electrical grid, and is largely classified by which side of an electricity customer's meter it is installed at. Front of the meter storage has the battery installed at the transmission, or supply level of the electrical grid. These are installed at generation plants or at utility distribution substations. Behind-the-meter storage is installed at the consumer level. A behind-the-meter installation could be a battery wired into an individual home's electrical system, or a larger commercial building, or a neighborhood, if the installation was not owned by the utility and metering was done at the neighborhood level. Front of the meter utility demonstration projects and test cases of batteries have been occurring for many years, but home batteries, which are the focus of

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this investigation, have only recently become more widely available commercially and extensive research is not widely published yet.

There are studies that have evaluated the feasibility of home battery energy storage with solar, but the price, regulations, and overall industry are changing so rapidly that the results can change within the period of a year. To effectively evaluate battery energy storage in the market place, a review of previous studies, available technologies, and regulatory trends will be completed. An economic evaluation using an electricity consumer's data and solar production will be performed, as well as an evaluation of noneconomic factors. Based on this evaluation, a realistic market size will be determined and recommendations will be presented for increasing this market.

3.2 Background and Related Work

In 2016, there was an estimated 10,465 GWh of energy generated from small-scale residential solar installations; however for the first time, the rate of new installations fell from the previous year [1, 2]. This could be as a result of lowering tax rebates or feed-in tariffs.

In Australia, where sunshine is abundant and the electricity prices are higher than the United States and predicted to increase, there have been studies showing the promise of energy storage. One such study found that a household that consumes 16 kWh per day could go off-grid with 4 kW of PV solar and 11 kWh of battery energy storage, with a 40% PV utilization rate. This was profitable for all households, but a complete disconnection from the grid was not due to the upsizing of the equipment involved [3]. A study that monitored daily load profiles of 38 households in Australia found the payback periods of battery systems to be longer than the battery's usable life. The cost in the study used was $1400 Australian per kWh, or around $1102 USD but looking in at the updated pricing in Table 3.1, one can see that the prices have gone down [6].

In the emerging Australian market, there is an opportunity for consumers to become producers, or prosumers [7]. It was found that a household that consumes 10 kWh per day would benefit from 3 kW of solar and a 10 kWh (assumed 8 kWh usable) battery. The approach was conservative and assumed only 4 h of sun. To be totally off-grid would require 5 kW PV and a 14 kWh battery, but this was considered too costly. The authors argued that home producers could sell to their neighbors and that there was no need to build any future centralized generation. There are already some companies that manage groups of users and producers in local electricity transactions, which could be supplemented by communal electric vehicles [7].

Various studies have focused on the effects of electricity pricing. In Germany, a sensitivity analysis was performed on prices and found that with all of the PV lowering demand, the electricity companies are likely to raise prices. If per

Table 3.1 Commercially available lithium ion residential batteries [4, 5]

Battery	Available in the United States?	Type	Capacity	Cost
Tesla Powerwall 2	Yes	Li-Ion	14 kWh	Up to $11,450 including install
LG Chem RESU	Yes	Li-Ion	Up to 9.8 kWh	Starting at $9000
Mercedes	California only	Li-Ion	20 kWh	$13,000 including install
Nissan Xstorage	No, UK only	Li-Ion	4.2 kWh	$4500 including install
PowerVault	No, UK only	Li-Ion	Up to 6 kW	Starting at $3000
ElectrIQ	Yes	Li-Ion	10 kWh	$16,000 including inverter
Panasonic	No, Australia only	Li-Ion	8 kWh	Not available
Sunverge	Yes	Li-Ion	7.7–19.4 kWh	$800–$20,000
SimpliPhi	Yes	Li-Ion	3.4 kWh stackable units	Not available
Sonnen	Yes	Li-Ion	16 kWh	Starts at $9950
BMW	Not yet	Li-Ion	22 kWh or 33 kWh	Not available
Enphase	Yes	Li-Ion	1.2 kWh combinable units	Not available

kWh electricity prices are increased, the profitability of the PV with an energy system is increased, but if the flat rate (for connection) is increased instead, profitability will decrease [8].

A complete comparison was made of various sizes of both PV systems and batteries and evaluated in different energy markets with the result that increasing battery size lowered ROI in all cases. The Tesla Powerwall 2 was used, as it will be in this study, with the assumption that a new one would be purchased after 10 years at 60% of the current price to match the system's lifetime with a solar system's lifetime. In Germany, where feed-in tariffs are low, the battery still increased profit, even with a lower ROI. In Ontario, where high feed in tariffs still exist, the battery was not as advantageous as selling solar power back to the grid. In Austin, the price of electricity was low compared to the other two cities and it was not expected to change over the course of the simulation, so profitability was low and subsidies are still needed. The only case in which a battery was profitable was for households of high consumption, because a tiered rate plan exists and the battery kept the usage level below the next tier. A time of use plan was also simulated in Germany which increased the ROI and profitability of the battery. At the current price, only Germany's electricity market allows for batteries to be a strong economic decision [9].

3.2.1 Technology Trends

3.2.1.1 Lithium Ion

The most prevalent form of battery energy storage is lithium ion (Li-ion) batteries. Lithium Ion batteries have grown in use since they were invented 30 years ago, primarily because of the high energy density and large cycling abilities in comparison to previous technologies, such as lead acid or nickel cadmium. In 2016, 97% of energy storage installations were Li-ion and the industry saw a 70% price drop over 18 months [10, 11]. The price is expected to continue to lower, but the trend may not be consistent. The Li-ion market is expected to grow up to six times over the next 10 years, due to new energy storage demand [12].

One of the most well-known Li-ion players, Tesla, is expected to produce more Li-ion batteries a year than were produced worldwide in 2013 when the gigafactory is complete [11]. Prior to the gigafactory, 88% of all lithium ion battery cells came from China, Japan, and Korea [13]. It has been rumored that Tesla's current prices for batteries are around \$150–\$200 kWh, which was previously not anticipated until the year 2020 [14]. The rise of this empire and its cheap (relatively) prices means a potential for a new monopoly. One of the arguments in favor of distributed energy is that it will allow more parties to enter the energy market and that it will allow more freedom from government-regulated utilities for consumers and businesses. But with the advent of all of Tesla's new technology electric vehicles, solar roof, Solar City, residential home batteries, and utility scale batteries and inverters, there is the potential for the monopoly to simply shift from public to private.

Beyond Tesla, there are a number of companies that are becoming competitive and trying to break into the home battery market, some of which are outlined in Table 3.1. Other car vendors, such as Mercedes, are utilizing recycled car batteries as their home battery. This is an important strategy as it helps lower costs for the batteries as compared to building the cells outright [4].

Up until recently, many utility scale lithium ion installations were case studies or test sites, but due to California's push toward a high renewable and storage portfolio, in 2016 and 2017, Californian utilities have begun to start full-scale systems including Southern California Edison's 80 MWh Tesla Li-ion battery and SDG&E's 83.5 MW of energy-storage contracts [15, 16]. Although these installations are on the utility scale, their size helps to move the technology forward and increase production of lithium ion.

3.2.1.2 Other Technologies

At the utility level, it is generally accepted that pumped hydro and compressed air are the most understood and most cost-effective form of energy storage; however they have severe geographic restrictions [17]. As a result, the electrochemical solutions have become more thoroughly explored and implemented as a long-term solution.

Flow batteries are gaining traction with the increasing demand for large-scale storage and various utilities are beginning to implement in test sites. SDG&E recently commissioned a flow battery that will provide 2 MW for up to 4 h and Puget Sound Energy is installing Pimus Power flow batteries, who recently announced a new system with a five-hour duration at a price 50% less than the leading Li-ion systems [18, 19].

Lead-acid batteries make up 1.6% of the remaining 3% of installations that are not Li-ion. Although lead-acid batteries have been around since the 1960s, the technology has advanced more quickly in recent years to overcome slow-charging issues and increase efficiency. The raw materials are widely available, making them an appealing choice, but the lifespans for high-cycling applications are still at only around 3–4 years [19].

Lithium ion as a technology itself has become somewhat of a monopoly. The technology is moving so quickly and prices are falling so fast that small companies and new technologies cannot keep up, essentially wiping out alternative paths. One company, Aquion, which built salt-water batteries, recently filed for bankruptcy, despite a long list of powerful investors. When projects are already subsidized, as many battery energy storage projects are, it is difficult to justify spending more on a newer, more expensive technology [20]. With the demise of Aquion, there are very few major players with residential-scale batteries that are not lithium ion. Some are available internationally (specifically, Australia) such as the RedFlow Z cell, a flow battery, or the GridEdge Quantum, which is sodium nickel chloride [5].

Other potential technologies include sodium sulfur, which is expected to grow to 1450 MW worldwide by 2020, with major installations already in place in Japan. Zinc-air, which uses air as a cathode and zinc as the electrolyte, is used in a system in Indonesia that has been up and running for 5 years. The supplying company, Fluidic Energy, claims that the cost is 20–25% less than lithium ion [19]. One particularly promising discovery as recent as March of this year came from one of the original coinventors of the lithium ion battery, Dr. John Good enough. His team developed a solid-state battery that uses sodium, has three times the energy density of Li-ion and more cycling life, and eliminates the chance of short circuits from charging too quickly as Li-ion has. It is the first solid-state battery to operate in cold temperatures, and can operate as low as −20 °C [21].

3.2.2 Regulatory Trends

In 2017, there is a 30% federal tax credit for energy storage at the residential level if the electricity used to charge the battery comes from renewable sources [22]. The minimum required is 75% generated from renewable sources to get 75% of the 30% credit, then goes up from to 100% generated from renewable for 100% of the 30%.

Most state-level regulations on battery energy storage focus on the utility scale, or front of the meter. Hawaii, Maryland, Nevada, and New York have begun the discussion and proposed some legislature for incentives, but have not passed anything yet [23]. Florida passed SB 90, which excludes 80% of a battery from ad valorem taxation if installed after January 1, 2018 [24]. Massachusetts has launched the Advancing Commonwealth Energy Storage (ACES) program, which will award up to $1.25 million per project for commercially viable energy storage applications in behind-the-meter applications. Residential projects are not eligible for this funding unless it is aggregated for multiple households and centrally managed, but the state is working on developing the Solar Massachusetts Renewable Target (SMART) Program that will include incentives for energy storage for single households [25].

California is leading the charge in behind-the-meter storage applications with the Self-Generation Incentive Program (SGIP). The program releases funding in steps at specific dates and has a total of approximately $447.7 million allocated for energy storage, $57 million of which is specific to small residential. Small residential is considered to be less than 10 kW. The incentive for the next step of funding is $400/kWh, with some additional limits based on discharge duration [26].

In addition to rebates and tax incentives, there may be an economic benefit to batteries based on high electricity rates, time of day pricing, and net metering rules for selling back produced electricity. PG&E in California will pay approximately $0.097 per kWh generated, which is less than even their lowest time of use rate or tiered rate of $0.172 per kWh [27]. Since this new rule means a customer gets less for what they overgenerate, a battery becomes much more economically incentivized, because it will actually pay for itself over time. It makes even more money when implemented with a time of use rate plan, because it allows the user to charge the battery during the day, when solar generation is high, and use it in the late afternoon/early evening, when rates are high, but solar generation is low.

Zero Net Energy initiatives have the potential to affect the energy storage market, depending on the structure. The California Energy Commission defines a ZNE building as "An energy-efficient building where, on a source energy basis, the actual annual consumed energy is less than or equal to the on-site renewable generated energy" [28]. With this definition, there is no requirements on time of day usage, so the building could simply oversize a rooftop PV system to guarantee the generation is higher than the load of the building and no battery would be required to help the building meet this mandate. This additional PV load will require utilities to look at mitigation efforts for the grid technical issues that this brings. It is estimated that at a level of PV penetration at 30% of peak load, energy storage will be required to solve the technical issues at the distribution level [29].

In February 2018, FERC issued a ruling that allows energy storage to bid into the wholesale market. The order requires ISOs and RTOs to adjust their tariffs in such a way that energy storage can compete at the level of larger-scale generation, and take advantage of the support batteries can provide in frequency and voltage regulation [30]. The original version of the order included DERs, but the commission ruled to postpone the decision to gather more information. There are many technical challenges of allowing distributed resources to be aggregated as a "virtual power plant" and the power sold on the wholesale market. These challenges will take more time to evaluate [31].

3.2.3 Grid Challenges of High Residential Battery Storage Concentration

If battery storage is widely implemented in residential and commercial locations, the potential for an entirely new electrical grid structure arises. It is possible that consumers would consider giving up a utility connection completely. Just as landline telephone lines are becoming obsolete, in a very distant future, power lines might as well. In the near future, it is unlikely that many people will want to give up the security of having back-up power if the sun doesn't shine for days on end. In high-sun areas, blackouts may be minimized, but it is unrealistic that a solar-plus battery system will ever provide that kind of comfort in most of the United States. Even in Australia, where solar and battery storage have proved out to be economically feasible for a wide range of households, the cost of the size needed to go completely off-grid was found to be too large [3, 7].

As a result of the lowering load, but the inability to cut the costs of the actual grid itself, utilities are left to navigate the balance of maintaining reliability, while revenue decreases. The lost revenue due to customers supplying much of their own electricity could become a major problem for utilities, as households are still connected to the grid and still rely on having the option of obtaining power from the utility, but are actually being billed much less. Although the fuel costs for utilities are lowering, the equipment costs are still there, and in some cases rising due to the high cycling of power flowing in both directions. This has the potential to affect low-income customers the most. High-income customers can afford rooftop solar and energy storage, so their utility bill costs will be cut, but since utilities will still need to make a rate of return, they could raise electricity rates on those remaining customers that do not have solar.

Discussion presented up to this point has been centered on the capability of coupling a battery with solar. This presents the obvious issue for areas of the United States that have low irradiance levels. Although solar is becoming more widespread in the northern parts of the United States, in areas of high cloud cover and snow (covering the panels), the levelized cost of solar is not economic enough. There are utility installations that combine wind and battery energy storage, but the limitation on wind is that larger turbines are so much more efficient than smaller turbines, so in smaller installations, it would be more difficult to justify costs at the residential level, in addition to the large space and height requirements for a wind turbine. This disparity in amount of distributed energy between different parts of the grid can bring about new challenges with grid management. Centralized generation will have to be planned strategically as to not create large load flow changes during a severe weather event.

The management of distributed generation resources on the grid is the primary technical challenge facing renewable energy. Energy storage can both help this and make it more complicated. It can help by load shifting in areas of high distributed resource penetration, but it adds additional monitoring points and control nodes. California's Assembly Bill 327 required the three major utilities in California

(PG&E, SCE, and SDG&E) to evaluate the best places to locate distributed energy resources in their system, and as a result, a locational net benefit analysis (LNBA) tool is being developed. The tool is far from being done, and there are disagreements about the end goal/use of it [32].

Beyond load shifting at the customer level, if a home battery is to be used to help relieve the stress of a distribution grid and help prevent centralized generation plants from being built, it will likely require some control from the utility. This brings up many communication and security issues. Interfacing with different equipment using different protocols can cause interoperability issues. Aggregating battery loads would also require consumers to buy off on the utility having control of their system, which people may feel is an invasion of privacy. Anytime communication is added to something that is not used for communication, it also opens that device up for attack, making security a big challenge.

3.3 Economic Analysis of Home Battery Energy Storage

The purpose of this study is to simplify the economic analysis of an energy storage system to the point where the average consumer can evaluate the profitability and usage of a battery. This analysis will then be used to determine market size. Two methods are presented: one based purely on cost per warrantied kWh of the battery and one that looks at the daily difference in price paid for electricity between a consumer with solar and a battery, or with solar only. Although solar PV and battery energy storage are very closely tied together and are likely only practical when used in conjunction, in this way, the battery can be evaluated independently. It also gives an idea of how likely a consumer would be to retrofit their solar system with a battery, rather than package them together.

3.3.1 Warrantied Life Price

Based solely on warrantied energy potential, Tesla Powerwall can pay for itself if used with solar power that is already installed. The Tesla Powerwall retail price is $6200, plus an installation cost estimated to range between $800 and $2000 [33]. The total warrantied storage is 37,800 kWh when discharged once a day [5]. Assuming the highest install cost, this comes out to be $0.223/kWh. Factoring in the 30% tax credit, the cost lowers to $0.152/kWh. This is more expensive than the national average for electricity of $0.1255, but is cheaper than some states' rates [34]. Over the warrantied life of the battery, it is likely that electricity rates will rise, making the battery a better economic option, as further discussed in the next section. For comparison, the LG Chem is also evaluated in Table 3.2. Note that both of these cost breakouts assume there is already an inverter present and paid for with an existing solar system.

Table 3.2 Comparison of two commercially available home batteries [5]

Tesla Power Wall	
Total cost of installation + battery	$8200
Cost after 30% credit	$5740
Warrantied life	37,800 kWh
Cost/kWh over lifetime	$0.152/kWh
LG Chem RESU	
Total cost of installation + battery	$9000
Cost after 30% credit	$6300
Warrantied life	30,000 kWh
Cost/kWh over lifetime	$0.21/kWh

3.3.2 Day-to-Day Charging Economic Analysis

3.3.2.1 Data and Assumptions

To evaluate usage for an average consumer, a more detailed analysis is completed to ensure that the battery can be charged and discharged each day using a roof-mounted solar photovoltaic system as well as cover consumption.

This analysis utilizes real solar production and load usage from a home in the Portland, Oregon area, from a day in May of 2017 and a day in August of 2017. The homeowner has already paid for his 5.65 kW PV system. His load consumption is less than the national average of 30 kWh/day, but that is typical in areas of mild weather like Portland or California [35]. The usage curve on weekdays is shifted slightly later than average, but follows the trend of someone who wakes up in the morning, uses energy to get ready, then goes to work and the usage drops, then the consumption peaks again in the evening between getting home and going to bed. The homeowner does not own an electric vehicle. A naïve forecasting method was used for consumption: it is assumed that consumption will be the same or similar day after day.

It is assumed that the costs of the PV system have already been justified and accepted. This also means that the size of the PV system may not have been optimized for a battery or located for optimal battery charging and discharging, but located solely based on available roof space. The monthly cost to have electricity connected to a home is not included in this analysis, as it would be the same for someone who has a battery and someone who doesn't.

The electricity rates assumed were from PG&E's time of use plan [27]. Portland's rates were not used, because the area has a 1:1 net metering rule, meaning that any excess PV power generated directly translates to a credit and therefore, there would be no economic advantage to purchasing a battery. For the 10 year warrantied lifetime of a battery, an assumption on the increase of electricity rate was made based off the predictions of rate increase for the next 2 years by the U.S. Energy Information Administration (EIA) extrapolating as a linear trend [36]. The predictions that

Table 3.3 Electricity assumptions for economic analysis [27, 36]

Size of solar PV system	5.65 kWh
Current electricity usage	~20 kWh/day (less than national average)
Peak rate	$0.305/kWh
Nonpeak rate	$0.229/kWh
Feed in tariff	$0.097/kWh
Peak rate time	3–8 p.m.
Predicted rate of increase of electricity pricing	3.4%

Table 3.4 Tesla Powerwall 2 specifications [5]

Cost after tax credit	$5740
Maximum charge capacity	14 kWh
Minimum charge capacity	0.5 kWh
Round trip efficiency	90%
Discharges per day	1
Warrantied life	10

the EIA makes are considered "business as usual" and do not attempt to take into account any major changes in policy or electricity supply. In this way, the assumptions made for this study are ensured to be a lower-end benchmark for economic analysis. The forecasted rate of increase, along with the U.S. pricing, is lower than many other countries pursuing solar aggressively, such as Australia. Other studies have utilized a 5% increase, which was considered conservative as sources cited 7.5% [7]. The feed in tariffs can vary greatly and change quickly [9], but they were assumed to stay the same for the life of the battery. A summary of the rates, along with the other general assumptions, is provided in Table 3.3.

3.3.2.2 Battery Assumptions and Charging and Discharging Logic

The Tesla Powerwall 2 was used as the simulated battery, because data was easily accessible and it is available for purchase in the United States at the time of this study. The specifications used as a basis for the model are presented in Table 3.4. The efficiency of the battery was compensated for in the model in the net energy column, by only using 90% of the excess solar power to charge it. Although it is likely the battery will still have a high capacity at the end of its warrantied 10 years, only a 10 year period was taken into account, because that is what was guaranteed by the manufacturer.

There are a multitude of factors that can be considered when determining the logic for battery charging and discharging. Some involve keeping the battery charge above 20% to help with aging, some rearranging demand with smart home networks, and some that ensure the battery is fully charged at the beginning of the peak time period [3, 7, 37]. The various battery management schemes are not addressed in this

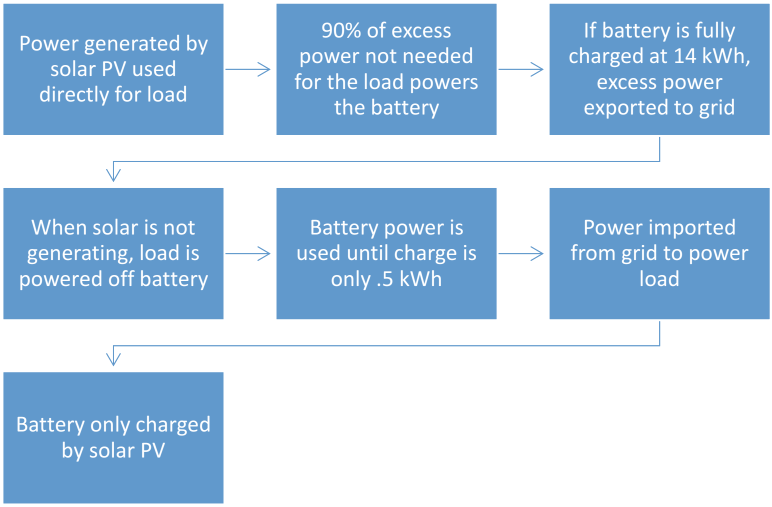

Fig. 3.1 Charging and discharging logic for economic model

analysis. Only a general economic feasibility is presented to esimate a number of households that a battery is a sound economic decision for. Some methods actually discharge the battery during peak electricity pricing times to make more money, but this method is focused solely on self-consumption. As mentioned above, the rate for selling excess power can vary greatly, and so the variable was attempted to be minimized in this case study by focusing on powering the load of the home itself, rather than prioritizing selling power back. If a battery was installed alongside and at the same time as the solar system, it could be optimized for this based on angle and location of the panels.

Figure 3.1 outlines the procedure for when the battery in the case study was charged and discharged. This analysis does not include sharp discharging for short times of cloud cover as the granularity of data received for power produced by the solar panels was not that small.

3.3.2.3 Methodology

To determine the cost of energy with and without solar, the following steps were taken:

1. The net usage for each 1 h period was determined by subtracting consumption from production. A negative value means more electricity was consumed than produced.
2. Apply net usage to load or battery, as per the process in Fig. 3.1

3. Revenue without the battery was calculated by importing or exporting the net energy at the time of use rate, or feed in tariff rate. A negative value means power was imported from the grid to the user.
4. Revenue with the battery was calculated by importing or exporting the excess power after completing the process above at either the time of use rate, or feed in tariff rate.
5. Each day of data was repeated to get a total energy purchased and a total energy sold
6. These typical days were then compared and an average for the revenue of each day was used to get yearly values

3.3.2.4 Results and Analysis

The base case utilized the cost factors summarized in Table 3.5.

When looking at the daily profile of the load of the home with and without the battery it was found that, as expected, with the battery, much less energy needed to be purchased from the utility. Although the battery resulted in the consumer importing much less power, there was also much less power exported to the grid, resulting in the negative difference in revenue from power production. When the two are netted, the battery still provides a benefit. If the battery can be charged up every day of the year, the internal rate of return of the battery purchase was 3% and the payback period was 9 years (Tables 3.6 and 3.7). The average values were determined by running the simulation over a 3-day period in both May and August. Three days was used to ensure the battery was discharged completely. It was found that in both May and August, the battery covered the entire load, but that in May, the battery was discharged to a lower level.

Table 3.5 Cost factors

Electricity rates	
Peak rate	0.305
Nonpeak rate	0.229
Sellback rate	0.097
Rate of increase of electricity tariff	3.4%
Battery price	
Price of battery	$8200.00
Tax credit	30%
Price after federal credit	$5740.00

Table 3.6 Daily average summary

Revenue	
Average difference revenue consumed per day	$2.78
Average difference in revenue produced per day	($1.30)
Average net difference in revenue per day	$1.48
Number of days battery is charged	365

Table 3.7 Base case results over battery lifetime

Year	Difference in revenue between system with and without battery—Consumed	Difference in revenue between system with and without battery—Produced	Total revenue
0			($5740)
1	$1014.65	($475.32)	$539.33
2	$1049.15	($484.66)	$564.49
3	$1084.82	($484.66)	$600.16
4	$1121.70	($484.66)	$637.04
5	$1159.84	($484.66)	$675.18
6	$1199.28	($484.66)	$714.62
7	$1240.05	($484.66)	$755.39
8	$1282.21	($484.66)	$797.55
9	$1325.81	($484.66)	$841.15
10	$1370.89	($484.66)	$886.23
Internal rate of return			3%
Payback period			9 years

Table 3.8 Summary of cost, charging days, and payback period

Cost of battery	Charging days	Payback period	Rate of return (%)
$5740	365	9 years	3
$5740	300	10 years	0
$1820	365	4 years	32
$1820	95	10 years	0

These results are limited in usability, however, because it is based on 356 days of a summer production profile, and in the winter it is much less likely that the solar panels will provide enough power to charge the battery fully and also supply the household load. To analyze a breakeven point, the number of charging days was adjusted to the point where the rate of return was 0%, which was found to be 300.

When evaluating the battery utilizing the SGIP incentives in California, the cost of the battery reduces to $1820, resulting in a rate of return of 32% for a full year of charging days. At that price, only 95 charging days are needed to breakeven. Table 3.8 exemplifies that the equipment costs are still a significant limiting factor to adoption.

As previously stated, there are many ways to optimize the battery charging and management. Since the feed-in tariff in this study is still higher than the difference in cost between the peak and nonpeak times, it is not advantageous to charge the battery from the grid for load shifting. The economic advantage can also be optimized by installing and pairing solar and a battery at the same time, and optimize angle of the panels with the load profile and peak times. Installing at the same time can also save equipment costs.

This study does not take into account nonfinancial benefits of having a home battery, such as the ability to not rely solely on the utility for power. In rural areas or areas where blackouts occur often, a battery paired with solar may be more cost-beneficial than a diesel generator over time, especially when taking into account the availability of fuel in an emergency.

Although not analyzed here, an option that may make a home battery more cost-effective is an agreement for demand response with a utility. In some residential areas, homeowners can volunteer load in their house to be shaved, or shut off in times of peak demand. A battery would allow for this shaving without necessarily losing a load in the house. If utilities can allocate the installed residential capacity as a reserve, it may help eliminate the need for building extra peak-time plants. This is a way for utilities to lower their costs, something that is a high priority as their revenue is decreasing. This combination of demand response and energy storage is being explored for industrial and commercial buildings by a partnership between CPower, who manages demand response, and Stem, a battery manufacturer [38].

3.4 Market Analysis: Residential Energy Storage

3.4.1 Current Market Size

Based on the economic analysis above, it was found that to break even on a home battery, the price of electricity has to be higher than the national average, and that net metering and tax rebates can help. There are very few states that have electricity rates close to those prices used in this economic analysis (Table 3.9).

Since the system was shown to charge the battery fully in the Portland, OR area, on a day in May without much excess, the average solar irradiance per day in May was used as a benchmark for irradiance level. This amount is 5–6 kWh/m^2/day. When overlaying the states that have this level year round with the states that have a high cost of electricity, it can be seen that only California and Hawaii (not shown) satisfy both requirements. Connecticut, Massachusetts, New Hampshire, New York, and Vermont are all at a range of 4–5 kWh/m^2/day, which is close and may be enough, but were not evaluated based on these results [40].

Table 3.9 Average cost of electricity for high-rate states in 2017 [39]

State	Average cost of electricity May-17 in cents
Hawaii	29.07
Alaska	22.04
Connecticut	20.94
Massachusetts	20.03
New Hampshire	19.61
New York	18.5
California	18.29
Vermont	18.04

Table 3.10 Total homes owned in advantageous battery states [41, 42]

State	Number of single family detached homes	Number of single family detached homes occupied by the owner
California	6,883,493	4,336,600
Hawaii	239,626	150,964
Total maximum homes in target market		4,487,564

To determine the market size with California and Hawaii, the total amount of single family, detached homes in each state was considered. This number was narrowed down by the amount of homes that are actually owned. This was done because it is more likely for someone to invest in their own home, and when they are the ones gaining the benefits. Since most people who rent pay for their own electricity bill, but the property is managed by someone else, it is not advantageous to the landlord to purchase a battery and pass the free electricity on to tenants. In July of 2017, the U.S. Census Bureau reported that 63% of homes were occupied by owners [41]. This rate was used for each state, although the homeownership rate likely varies by state (Table 3.10).

By narrowing down states with high solar irradiance, high electricity rates, and determining the number of owned homes, the maximum market size is 4.45 million homes. This however is still unlikely, considering other factors like upfront cost, size constraints, and the effort needed to just merely apply for a battery with the interconnecting utility. All of the analysis thus far assumes the purchaser has the assets on hand to be able to purchase the equipment upfront. The model is simplified becasue it does not take into account the additional interest with leasing or financing the battery. Even if the cost of the battery may prove out over its lifetime, the upfront cost of purchase and install are a burden, especially combined with the cost of solar, and limit potential adopters further.

3.4.2 Market Potential

3.4.2.1 Community-Scale Storage

There is potential to increase the market of home batteries by implementing solar and storage at the neighborhood level. Doing this would help take advantage of some economics of scale and it has been shown to be more economical for larger groups, up to 100 homes [43]. It also helps even out demand spikes because of the larger capacity and the relative change would be less from one house doing a higher-energy task. Challenges involved in community solar involve how to buy in and how to split up the power, and what power to guarantee.

A case study of distribution level solar and storage done by KCP&L in Kansas City found the challenge to not be in the excess, but in islanding situations. They did not know who to dispatch the power to in the case of a blackout and recommended battery storage at the home level to avoid this issue. Through analysis of this test site, the KCP&L team recommended 4–5 MWh of storage capacity for every MW of capacity [44]. If a factor of four times is extrapolated from the KCP&L report, then for a typical 4 kW solar system, 16–20 kWh would be needed. This is not much more than a single Tesla Powerwall, but if the goal is to combine 100 homes of electricity use of that size, land space becomes a challenge for community solar and storage. Unless a neighborhood is willing to give up a corner of the nearby park, rooftops and garages look more desirable for tucking these systems away.

3.4.2.2 Low-Income Subsidies

There are large opportunities for battery energy storage to aid in energy equity. There are already subsidies in place to help low-income families pay their electric bill. If these subsidies were transferred or augmented to help pay for solar systems and batteries, it could benefit society overall and could lower the financial burden, as once both systems are paid off, the subsidies are no longer needed. Systems like this may also help raise awareness of energy consumption, because it would put a cap on the "free" energy from the solar system and the battery, and would limit the desire to go over this amount and have to pay full utility prices. The challenges in this are the larger upfront cost required to install the solar and battery, rather than the lower monthly cost of an energy bill; however, if the SGIP was use for low-income housing, the battery cost would be paid off in 3–4 years. These could also be coupled with low-income housing projects.

In some states, there are specific rebates for solar earmarked for low-income families in either single family or multifamily dwellings, but nothing that includes storage yet. The California Energy Commission (CEC) is considering focus on low income for new rebates however [23]. Even the solar incentives are difficult to implement, as it is a maze of paperwork and extensive qualifications. One company in New Orleans, Posigen, has made its name by helping low-income households install solar by streamlining the process. Battery energy storage could easily be paired with the system and be more widely implemented in this way. There are still many technological challenges involved with implementation however, such as when back-up power is needed from the utility, and the cost that would come along with that, or retrofitting a home to have essential home functions (such as refrigeration) on one circuit and nonessential on another circuit.

3.5 Recommendations

Battery energy storage, as a whole, is still at the early adopter stage of the technology adoption curve. On the residential side, it is barely even at that stage. By focusing rebates on homeowners only, the market is limited. Almost 40% of dwellings in the United States are not freestanding homes [42]. To encourage higher adoption rates, rebates and incentives should shift to communities and multifamily dwellings such as condominiums, townhouse complexes, and apartment buildings. The United States can follow Australia's lead and provide opportunities for private businesses to emerge and manage these energy transactions.

These new management schemes will ultimately have to be coordinated by the utility at the top level [7]. The utilities will never completely go away as people will still depend on them periodically. They will need to adapt by implementing a new rate structure that no longer depends on large amounts of energy all the time to make money, because higher electricity costs will only lead to higher adoption of distributed energy, which will only lower their revenue. They should start by revamping the distribution level interactions and make transactive energy profitable for them. The slow adoption rate of batteries will give utilities and regulatory bodies time to prepare for these new scenarios, rather than react after it is too late.

Utilities could take advantage of home batteries by leasing them to customers but still accessing them during peak times to decrease load through demand-response programs, or by leasing batteries to customers. Green Mountain Energy has paired up with Tesla to provide a program where customers can lease a battery and add a monthly fee right into their bill. This allows the utility to put the equipment into the rate base and utilize the monthly payments to offset a part of the annual revenue requirement [45]. In order to create programs like this, the state has to be fully committed to green electricity and utilities will need to innovate their rate structure.

Batteries are already close enough to being economically viable that middle-upper class home owners may not need significant subsidies to adopt. Instead of large subsidies (like California's $400/kWh incentive) that go to few users, a smaller incentive, spread across more people, may be all that is needed. These tax credits must be carefully managed and put into place with a plan for slowly phasing them out as to prevent market volatility [46]. Small credits, along with regulations and credits for net zero energy new construction, will slowly build the market. Zero Net Energy mandates should include a maximum peak energy load, and require below a certain load profile, rather than just requiring all energy to be offset at some time. This will increase battery adoption and will keep peak loads on feeders lower.

For existing solar programs, there is criticism that subsidies move wealth from other low-income programs to the wealthy, because it is still primarily the wealthy that take advantage of the credits, and it diverts money that could be utilized somewhere else. This same argument can be made of battery storage. This issue, along with the fact that higher rates of solar and battery adoption will likely increase the price of electricity for those who are still solely dependent on the grid, may cause a sharp divide between the wealthy and the poor in energy usage. Existing energy subsidies and low-income housing incentives should be coupled with battery storage incentives to increase adoption. When building new low-income housing, batteries should be included upfront, as even though they are expensive, they would only add marginally to the cost of building large density housing. Programs like SCE's Energy Savings Assistance Program, which currently offers free energy-efficient appliances based on income level, should be expanded to include solar and battery storage.

3.6 Conclusion

Greentech Media expects an expansion of 12 times for the market, from 221 MW in 2016 to around 2.6 GW in 2022, 53% of which will be behind-the-meter installations [23]. There have been comparisons of battery energy to solar adoption curves, but as energy storage has more uses and different uses, they will very likely diverge [47].

Based on the technology, regulations, economics, and challenges presented in this study, further policy and incentives are recommended in order to implement battery energy storage at a wide level and the following is surmised:

- Although previous studies are mixed on the viability of energy storage, the technology is rapidly evolving and the costs are dropping, making it more economically feasible
- At the current state, only areas of high irradiance and high electricity rates make the battery a good investment
- This market area can be expanded by restructuring rebates in California, and adding rebates in other areas that are right on the edge of economic viability:
  - Expand rebates and restructure to make battery storage adoption advantageous to property managers, and multifamily housing units by incentivizing energy management
  - Utilities will need to update their structure and innovate, by coordinating energy movement between neighbors and communities more at the distribution level
  - Batteries in areas like California are so close to being economically viable with just federal rebates, that the state SGIP rebates should be lowered and spread out more
  - These diverted funds from the current large rebates can be coupled with low-income housing subsidies and energy bill payment subsidies to implement batteries at the lower-income level
  - ZNE mandates and initiatives should be more strict on loading times, potentially requiring the building to include a battery

An important piece of the puzzle, that requires much forward thinking and planning, is the disposal and recycling of battery materials. Batteries degrade over time, and at some point, they will lose their charge. Many promises of recycling have been made, but until the time comes to actually do it, it is difficult to forecast how it will actually shake out.

For a long time, energy storage has been regarded as the holy grail of power generation: if you can store energy, the future of clean, cheap, renewable energy is secure, but it is only now that it is really beginning to gain traction in the industry. Battery energy storage has come a long way in a relatively short amount of time, but still has major challenges to overcome. Batteries will need to be economically viable at all income and housing levels, to avoid a situation that only increases the disparity between rural and city, or wealthy and poor. Lithium ion batteries are picking up speed as the standard installation, which is lowering costs but also driving out competitors. Although there is a lot of progress in areas like California, most of the United States is not pursuing battery storage at the residential level, because it is still not economically viable.

Appendix: Results

Daily Profile Summaries

Demand: August day	W/o battery	W/battery	Difference
Number of kWh purchased at peak	−0.25	0.00	0.25
Number of kWh purchased at nonpeak	−11.61	0.00	11.61
Number of kWh sold	16.02	2.86	−13.16
Revenue at peak	−0.08	0.00	0.08
Revenue at nonpeak	−2.66	0.00	2.66
Revenue from energy sold	1.55	0.28	−1.28
Energy revenue	−1.18	0.28	1.46

Demand: May day	W/o battery	W/battery	Difference
Number of kWh purchased at nonpeak	0.00	0.00	0.00
Number of kWh purchased at peak	−12.33	0.00	12.33
Number of kWh sold	14.21	0.52	−13.69
Revenue at peak	0.00	0.00	0.00
Revenue at nonpeak	−2.82	0.00	2.82
Revenue from energy sold	1.38	0.05	−1.33
Energy revenue	−1.45	0.05	1.50

Economic Analysis Base Case

Electricity rates	
Peak rate	0.305
Non peak rate	0.229
Sellback rate	0.097
Revenue	
Average difference revenue consumed per day	$2.78
Average difference revenue produced per day	($1.30)
Number of days battery is charged	365
Rate of increase of electricity tariff	3.4%
Battery price	
Price of battery	$8200.00
Tax credit	30%
Price after federal credit	$5740.00

Year	Difference in revenue between system with and without battery—Consumed	Difference in revenue between system with and without battery—Produced	Total revenue
0			($5740)
1	$1014.65	($475.32)	$539.33
2	$1049.15	($484.66)	$564.49
3	$1084.82	($484.66)	$600.16
4	$1121.70	($484.66)	$637.04
5	$1159.84	($484.66)	$675.18
6	$1199.28	($484.66)	$714.62
7	$1240.05	($484.66)	$755.39
8	$1282.21	($484.66)	$797.55
9	$1325.81	($484.66)	$841.15
10	$1370.89	($484.66)	$886.23
Internal rate of return			3%
Payback period			9 years

Economic Analysis: 300 Days of Sun

Electricity rates	
Peak rate	0.305
Nonpeak rate	0.229
Sellback rate	0.097
Revenue	
Average difference revenue consumed per day	$2.78
Average difference revenue produced per day	($1.30)
Number of days battery is charged	300
Rate of increase of electricity tariff	3.4%
Battery price	
Price of battery	$8200.00
Tax credit	30%
Price after federal credit	$5740.00

Year	Difference in revenue between system with and without battery—Consumed	Difference in revenue between system with and without battery—Produced	Total revenue
0			($5740)
1	$833.96	($390.68)	$443.28
2	$862.31	($398.35)	$463.96
3	$891.63	($398.35)	$493.28
4	$921.95	($398.35)	$523.60
5	$953.29	($398.35)	$554.94

(continued)

Year	Difference in revenue between system with and without battery—Consumed	Difference in revenue between system with and without battery—Produced	Total revenue
6	$985.71	($398.35)	$587.36
7	$1019.22	($398.35)	$620.87
8	$1053.87	($398.35)	$655.52
9	$1089.71	($398.35)	$691.36
10	$1126.76	($398.35)	$728.41
Internal rate of return			0%
Payback period			10 years

Economic Analysis SGIP Program

Electricity rates	
Peak rate	0.305
Nonpeak rate	0.229
Sellback rate	0.097
Revenue	
Average difference revenue consumed per day	$2.78
Average difference revenue produced per day	($1.30)
Number of days battery is charged	365
Rate of increase of electricity tariff	3.4%
Battery price	
Price of battery	$8200.00
Tax credit	$400/kWh + 30%
Price after federal credit	$1820.00

Year	Difference in revenue between system with and without battery—Consumed	Difference in revenue between system with and without battery—Produced	Total revenue
0			($1820)
1	$1014.65	($475.32)	$539.33
2	$1049.15	($484.66)	$564.49
3	$1084.82	($484.66)	$600.16
4	$1121.70	($484.66)	$637.04
5	$1159.84	($484.66)	$675.18
6	$1199.28	($484.66)	$714.62
7	$1240.05	($484.66)	$755.39
8	$1282.21	($484.66)	$797.55
9	$1325.81	($484.66)	$841.15
10	$1370.89	($484.66)	$886.23
Internal rate of return			32%
Payback period			4 years

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Chapter 4
The Adoption and Use of Tethered Electronic Personal Health Records for Health Management

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4.1 Introduction

Information Technology becomes a crucial part of the health-care system and it is getting more attention worldwide. Health IT includes well-known systems that have transformed the health sector such as Electronic Health Records (EHR), Electronic Medical Records (EMR), and Electronic Personal Health Records (ePHR). ePHR aims at enabling patients to take more active role in their care by giving them the ability to access their health records in a secure and safe environment. ePHR allows greater patient-provider engagement. The provider's adoption rate of the ePHR as a tool to connect with patients and to enable them to have access to their records is increasing at an accelerated rate. However, the patient's ePHR adoption rate remains low. In the USA, the Office of the National Coordinator for Health Information Technology (ONC) reports an increase in the number of office-based physicians' and hospitals' adoption of the EHR. The number of office-based physicians adopting EHR increased from 17% in 2008 to 58% as of 2015. Similarly, it shows that the nonfederal acute care hospitals with certified EHR rate increased from 9% in 2008 to 84% as of 2015 [1]. Despite the efforts to encourage the health-care providers' adoption of certified EHR and ePHR, the adoption rate by patients remains below expectations [2]. This rate is expected to increases due to the wide attention and efforts led by governments and health-care providers to engage patients in their care. The forecasts of future ePHR adoption are expecting 75% of adults to adopt and use ePHR by 2020 [3]. More attention is needed to improve the patient's adoption of ePHR.

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4.2 Definition

There have been many health-care professionals and organizations that have introduced different definitions to the ePHR. The Markle Foundation's Connecting for Health, a public-private collaborative, is a program that consists of a group of experts and Personal Health Workgroup (PHWG) formed to discuss several aspects of the Personal Health Records including the benefits, barriers, and consumers' perception of its values [4]. The Personal Health Working Group (PHWG) defines ePHR as

> an electronic application through which individuals can access, manage and share their health information, and that of others for whom they are authorized, in a private, secure, and confidential environment.

The ePHR definition implies several characteristics that include [4]: ePHR is owned and controlled by the patient and whom the patient authorizes, the patient has access to the ePHR at any time from any place, ePHR is transparent, and ePHR contains lifetime health information of the patients from the health-care providers.

The type of ePHR mentioned throughout this report is the one that is tethered to the health-care provider's Electronic Health Record which also would mean the patient portal [5]. Patient portal and ePHR have the same meaning. The Office of the National Coordinator for Health Information Technology (ONC), whose responsibility is to support the adoption of Health Information Technology, has used the ePHR and patient portal terms interchangeably [6]. Thus, this report will use both terms, ePHR and patient portal, interchangeably.

4.3 Health Information Technology

Health information technology (HIT) allows the health-care providers to benefit from the information and communication technology advancements to better manage their patient care using computerized systems. HIT allows for the secure use and sharing of important health information which improves health-care decision making and ensures high quality care. Among the computerized systems that have transformed the health sector are the Electronic Medical Records (EMR) and Electronic Health Records (EHR) as they serve as the base of the ePHR. Electronic Medical Records (EMRs) contain all the patient's health information; health problem lists, lab results, physician notes, and radiology results; from a single health-care provider so that the patient may have multiple EMRs from different hospitals or physician offices [4]. The US Centers for Medicare & Medicaid Services defined the Electronic Health Record (EHR) as "*an electronic version of a patient's medical history, that is maintained by the provider over time, and may include all of the key administrative clinical data relevant to that person's care under a particular provider, including demographics, progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data and radiology reports*" [7]. What differentiates the EHR from EMR is that EHR contains patient's health records from multiple health-care providers. The benefits of EHR include: improved patient health care, increased patient engagement, improved efficiency and cost reduction, improved quality of care and outcomes, and improved care coordination [8]. In this report, Electronic Personal Health Records is the one that is tethered to the health-care provider's electronic health record as it is the same as the patient portal [9].

To achieve the purpose the ePHR was designed for, it must be adopted, accepted, and used by the patients. The adoption of ePHR can be measured to represents the adoption level in two ways which are the number of patient login into the portal and the intention of the patient to use the ePHR portal data coming from surveys [5].

4.4 Types of ePHR

Patients are encouraged to take more active role in their health-care and government initiatives direct their effort to support the patient-centered health care. PHR enable patients to be involved in their care and be able to access and manage their health information. PHR can take many forms from paper-based to electronic-based that can be stored in a computer or on the cloud. The selection of the appropriate PHR form from the patient's perspective may be influenced by the convenience of usage, the ease of access, update, and maintain, and how easily they can be shared with health-care providers. There are several types of PHR that support the patient empowerments. The following are the types of PHR [10]:

- *Paper-Based PHR*: It is considered as the old way of keeping track of one's health information. PHRs in this case are files or folders that contains information from doctors, pharmacies, and hospitals that are kept as a reference.
- *Personal Computer-Based PHR*: This kind of PHR involves the patients downloading a software in their computer and then store their health information in an electronic form. This kind of PHR provides the convenience of updating or printing their health information.
- *Internet-Based PHR*: Majority of today's PHRs are Internet based. Patients access PHR by creating a PHR account and logging in with their unique credentials. Through this kind of PHR, patients can organize their health information in an electronic format. It is easy for the patients to update and maintain their PHR and even share their health information with their health providers online.
- *Hybrid Personal Computer-Internet PHR*: This kind allows the patients to store their health information in their personal computer and then transfer them to an Internet account in case they are needed or share their health information with their provider through the Web.
- *Health-care Provider PHR*: This kind is the tethered electronic personal health records where the patients have access to their health information from their health-care provider's electronic health records. This kind of PHR also called a patient portal.

Another classification of PHR is whether these PHRs are tethered to an EHR or not. There is a difference in the management and shared information between the electronic Personal Health Records "ePHR" and tethered electronic personal health records or what is known as patient portals. Tethered ePHR is linked to the provider's Electronic Health Records "EHR." In this case, the data in the EHR is transferred and populated to the ePHR or the patient portal for the patients to access and manage. This health information may include health history, lab tests/results, and appointments [5]. On the other hand, untethered ePHR is either owned and managed by the patient which means that the patient populates the data to the ePHR or allow data to be entered or transferred to the ePHR [5]. Studies show that patients tend to use ePHR that is hosted, managed, and accessed by their doctors. They do not have interest in their insurance company, employer, or the government to maintain their records [4]. Patients can have stand-alone commercial PHR in which they can enter and access their data. As the stand-alone advances, certain PHR functionality can be added by connecting the commercial PHR to the provider's EHR in order for the patients to view and access their health information from certain provider [11].

4.5 Importance of ePHR Adoption

The ePHR has generated several important benefits. ePHR enables patient-centered health-care, improved efficiency, improved quality of care, and reduced cost. ePHR facilitates patient engagement in their health. The Agency for Healthcare Research and Quality defines patient engagement as "the involvement in their own care by individuals (and others they designate to engage on their behalf), with the goal that they make competent, well-informed decisions about their health and health care and take action to support those decisions" [12]. The ePHR offers set of capabilities that support patient engagement in their own health care. The Institute of Medicine emphasizes the patient-centered care as one of the health-care improvement aims [13]. Furthermore, patients should have full access to their health records and the smooth flow of information is ensured. It is believed that the ePHR will improve patient engagement which will have a positive impact on the care outcomes and help reducing health-care costs [14]. ePHR helps health-care providers deliver better quality care as it improves the patient-provider relationship, allows more flexible and efficient access and use of services, and decreases some risks as it reduces errors [15]. The ability of the patient to access a wide variety of information regarding their health is considered as one of the essential benefits of the PHR [11]. Patients recognize the value the ePHR generate to them as 71% of the patients believe that it helped them understand the physician's instructions, 65% believe ePHR helped in preventing medical errors, 64% of patients believe ePHR allowed them to have more control over their care, 62% of patients think ePHR helped them to communicate their issues effectively, and 60% of patients revealed that it helped them to change the way they take care of themselves [4].

ePHR from a financial perspective is deemed to help in the cost reduction of the health care. The growth of the health sector expenditure mandates finding new ways to provide high quality care while reducing cost. The USA spending on the health-care sector, as a leader in the health area and health IT, was $3.3 trillion in 2016, growing by 4.3% which represents about 17.9% of the nation's GDP [16]. In the USA, The American Recovery and Reinvestment Act of 2009 (ARRA) focuses on the health information technology-related funds [17]. The health care IT sector was aided by over $20 billion to support the development of health IT infrastructure and to encourage involved parties to adopt and use health IT [17]. The ARRA Act considers the EHR and ePHR as significant elements of the national policy aiming at achieving the goals of improving the quality of care, safety, efficiency, and reducing costs. ePHR has been recognized as an essential element of the national and global initiatives that aims at developing and implementing of health IT solutions. ePHR helps to avoid unnecessary or duplicated tests or labs. One study showed that such a computerized system helped to block about 11,790 unnecessary duplicate test orders in just 2 years that would have costed around $183,586 [18]. It helps reduce staff workload which means low cost of overhead [19]. ePHR tends to help in providing a better quality of care and provide service and treatments which in consequence helps reduce costs [15]. It decreases unnecessary consultations and waiting lists as well [15]. Patients can benefit from the online prescription ordering service offered as part of ePHR which in return would improve the efficiency of the pharmacists work and reduce the time spent fulfilling the prescription in the traditional way [15]. ePHR can be used to deliver some administrative services that would be costly to do in the traditional way such a cost saving comes from: lab/test results mailing cost, online billing inquiries in compared to making phone calls, online appointment scheduling, appointment reminders, and phone calls [20]. Studies showed increase in the productivity due to physicians using the electronic media to communicate with their patients. One study found out the physicians' productivity increased by 10% and they were able to see more patients per day [21]. Kaelber and Pan studied the value of PHR Systems and concluded that PHR can provide net benefit to the US health-care system through $11 billion annually in expected cost savings [22].

4.6 Capabilities and Features of ePHR

ePHR offers many features for the user to utilize. Such features include allowing patients to access their health information from their provider's EHR, recent doctor visits, discharge summaries, medications lists, immunizations, communicate with their providers with secure messaging, request prescription refills, review lab/tests results, schedule medical appointments, and access educational materials [6]. Secure Messaging feature facilitates the communication with the health-care providers to better assist informed health decisions and is considered one of the most used collaborative communication features by patients [23] alongside with medication reconciliation [5]. Also, secure messaging meets one of the objectives of the meaningful use stages 2 and 3 [23]. The meaningful use stage 2 requires that 5% of the health-care providers patients' population use secure e-messaging in order to qualify for the meaningful use stage 2 incentives [5, 24]. Secure messaging allows access to health care without, in many cases, the need for in-person visits as well as improving the quality of the doctor visits [25]. Communication tools allow patients to take an active role in their health care and improve the relationship with their providers. The Foundation for Accountability (FACCT), as part of the Markle Foundation's Connecting for Health program, studied the ePHR functionalities and their usability by surveying 1246 online individuals between 2002 and 2003 [4]. The features of the ePHR that were tested are messaging doctors, checking immunizations, note mistakes in one's record, transfer information to new providers, and test results. The findings showed that over 70% of respondents have interest in using one or more features of the PHR, 35% would use seven or more features if it were available, 75% use ePHR to communicate with doctors through e-mail, 69% to track immunizations, 69% to track mistakes in their records, 65% to transfer information to new health-care provider, and 63% to check the test results.

Individuals' interest in utilizing information technology in their health care is growing significantly. There are notable trends in the individuals' use of health IT in the USA between 2012 and 2014. People use technology to communicate with their health-care provider, check their health information, and track their health. The statistics provided by the Office of National Coordinator (ONC) for health information technology shows that almost half of the Americans by 2014 used a type of health IT [26]. The literature shows an increased use of technology by people to perform certain types of related health activities such as communicating through text message or e-mail with their health-care provider, using smartphone health application, and/or checking medical test results online [26]

Between 2012 and 2014, the percentage of individuals who used text messages to communicate with their health-care providers grew from 6% in 2012 to 11% in 2013 and 18% in 2014. Using smartphone health applications rose to 17% in 2014. Almost 22% of people checked any of their medical test results online in 2014 compared to 13% in 2012. Finally, 31% of individuals sent or received an e-mail message from their health-care provider in 2014 as compared to 23% for the years of 2012 and 2013. People use of one or more of these types of IT for their health grew between 2012 and 2014, from 35% to 48% [26].

4.7 Impact of ePHR on Health Outcomes

There have been debates on whether ePHR provides positive impacts on the health outcomes or it is just a tool that gives patients access to their health information, improves the patient-provider communication, and keeps the patients engaged with their health information. A systematic review study looked at the effects of the ePHR on the clinical care outcomes concluded that there is no sufficient evidence to support the claim that ePHR improves health outcomes [27]. Another systematic review conducted to study the impact of health IT on the quality, efficiency, and costs of medical care showed an indirect impact of the quality on the health outcomes as ePHR helps decreasing medication errors [28]. The impact of the ePHR on patient care was investigated through systematic review study [29]. The study found out that “There were no statistically significant changes between intervention and control group in the 2 randomized controlled trials investigating the effect of patient portals on health outcomes” [29]. It concluded that the impact of the ePHR on the clinical care cannot be determined by based on the existing literature. In a higher scope, a systematic review studying the impact of health IT and health information systems on the patient health outcomes aligned with the previous literature by indicating insufficient evidence of the ePHR impact on the clinical outcomes either clinically or statistically [30]. There have been some studies that have tried to measure the contribution of the ePHR to the overall outcomes. Another way outcomes can be measured is through the evaluation of the hospital admission rate, patient knowledge, and involvement, and improved treatment adherence [23]. In the case of chronic diseases, ePHR can improve the quality of the health by providing customized educational materials and self-management tools as well as improving the patient-provider communication [23]. It is clear that more studies investigating the effect of the ePHR on the health outcomes are required.

4.8 Current Adoption Status

The adoption level by the health-care providers is increasing at an accelerating rate. However, the patient adoption and access to the patient portals remains low. For example, in a study conducted on the University of North Carolina HealthCare System on 2016, among 2,975 patients, only 8% were classified as active users and 8.6% were light users [23]. The study found out that the active users logged into their portals on average of 34 times per month and used the messaging feature about 108 times per months as well as viewed their lab results 76 times per month following the discharge month. Additionally, most of the discharged patients did not login into their accounts within the following 30 days of the discharge date as well [23]. The Office of National Coordinator (ONC) for health IT developed a government initiative called the health IT dashboard to allow access to a variety of health IT dashboards such as interactive data, downloadable information, and relevant statistics [31]. The health IT dashboard consists of open data sets resulting from government-sponsored surveys and initiatives; a library that contains the ONC data briefs, evaluations, reports, and plans; and statistics obtained from national surveys referred to as “Quick Stats” which represent the key health IT data and statistics providing access to facts and figures about health IT [31].

It is important to mention that the Center for Medicare and Medicaid Services launched “Meaningful Use” initiative and created an incentive program to foster the adoption of Electronic Health Record (EHR) and patient engagement systems for clinicians and hospitals who meet certain criteria and measurements that aims at improving the quality, safety, and effectiveness of care [32].

Quick Stats has data about adoption, exchange and interoperability, patient access, public health reporting, and safety and security [33]. The adoption of tethered ePHR relays on the existence of the Electronic Health Records (EHR). Office-based Physicians and Hospitals seek to adopt certified EHR to meet the objective of the "Meaningful Use" and qualify for the incentive program as well as to provide a high quality of care. The following section shows the ePHR adoption rate in the USA.

4.8.1 Office-Based Physician Electronic Health Record Adoption

There are three classifications of EHRs that are adopted by the office-based physicians [34]: EHR is classified as "Basic EHR" when the physicians reported their clinics utilizing the following functions: patient demographics, patient's health history, patient's list of medications, Doctors notes, orders for medications, laboratory tests results, and imaging results. "Any EHR" is the classification of the health record systems that have the "Basic EHR" functionalities but excludes systems only for billing. "Certified EHR" is the system that is adopted by the US Department of Health and Human Services and meets its criteria. The literature shows that as of 2015, about 87% of the office-based physicians adopted any EHR, 78% a certified EHR, and 54% adopted basic EHR. The level of adoption between the year of 2004 and 2015 has doubled and tripled for both any EHR and basic EHR. For the certified EHR, the Office of National Coordinator (ONC) and the Centers for Disease Control and Prevention (CDC) began tracking the adoption rate by office-based physicians in 2014 [34].

4.8.2 Office-Based Physician Electronic Patient Engagement Capabilities

EHR adopted by the office-based physicians should provide patients with certain engagement capabilities to meet its objectives. Patient engagement aspects of the EHR include giving the patients the ability to exchange secure messages with their physicians and to view, download, and transmit their online record [35]. The literature shows that about 64% of office-based physicians had an EHR with the capability to communicate with their patients using secure messages; 63% of office-based physician's EHR allows the patients to view their records, 41% to download their records, and 19% to transmit their records to a third party; and only 16% of office-based physicians with EHR that provide the patients with the capabilities, all together, to view, download, and transmit their medical records [35]. These statistics shows an increase in the adoption and utilization of EHR capabilities by the physicians to engage patients in their health care as compared to previous years, 2013 and 2014.

4.8.3 Physician Electronic Exchange of Patient Health Information

The National Center for Health Statistics conducted surveys in 2014 and 2013 to investigate the office-based physicians' electronic sharing of patient health information that shows the increase in patient engagement by utilizing their ERH capabilities [36]. According to the literature, 57% of physicians electronically shared health information with their patients in 2014 compared to 46% in the year of 2013. Fifty-two percent of physicians exchanged secure messages with their patients in 2014 with an increase of about 30% than the previous year. The percentage of physicians who provide the patients with the ability to view, download, or transmit their electronic health information was 33% in 2013 and increased to 47% by 2014 [36].

4.8.4 Percentage of Hospitals, by Type, that Possess Certified Health IT Solutions

On the other hand, hospitals seek to acquire certified health IT as well. More than 90% of all hospitals had certified EHR system as of 2015 [37]. The literature shows that 98% of the large hospitals with 400 or more beds have the highest rate of possession of certified EHR followed by the medium hospitals, 100–399 beds, with 97%. Ninety-six percent Critical Access hospitals had certified EHR. Small rural and urban, less than 100 beds, hospitals had the lowest rates at 94% [37].

4.8.5 Hospital EHR Adoption

The release of the incentive program by the Center for Medicare and Medicaid Services has fostered the EHR adoption rate by the hospitals. As of December 2013, 4,400 hospitals (87%) of all US hospitals had qualified for at least on incentive payment from the Center for Medicare and Medicaid Services programs [38].

4.8.6 US Hospital Adoption of Patient Engagement Functionalities

Hospitals adopt EHR and utilize its patient engagement capabilities and functionalities to improve the quality of care provided. The Center for Medicare and Medicaid Services provides incentives to the hospitals that utilize certain functionalities, such as view, download, transmit health information, and allow secure messaging with their providers [39]. The EHR also consists of other functionalities that are useful to the patients but are not included in the incentive program such as update health information, pay bills, schedule appointments, request prescription refills, and submit patient-generated data [39]. It is clear, according to the literature, that there is significant increase in the percentage of hospitals that allow patients to view, download, and transmit their health information online (about 69% of the hospitals in 2015) as well as using secure messaging to communicate with the patients (63% of the hospitals in 2015) [39]. This significant growth is attributed to The Center for Medicare and Medicaid Services incentive program as it fostered the adoption and utilization of the EHR and patient engagement functionalities.

4.9 ePHR Adoption Barriers

There have been recognized barriers to adoption from the perspective of the hospitals as to implement the ePHR and from the patients' perspective as they adopt and use it in their health care. The high cost of the ePHR implementation and maintenance may hold some providers from adopting ePHR [22, 40]. This may have changed as a result of the incentive program for meaningful use [40]. Other implementation barriers include privacy and security issues [41]. Physicians play a key role in the widespread of the ePHR as they can influence the patient's decision in adopting and using the ePHR. Physician's perceptions of the ePHR adoption are important to be addressed. Physicians perceive the low patient computer and health literacy; patient motivation to adopt ePHR, and the interoperability between the systems as the main barriers to adoption [42]. Physicians perceived the level of control that patients may have over their ePHR as barrier. They believe that patients should be granted read-only access rather than being able to enter or modify data that might be inaccurate or lead to unfavorable decisions [43].

The barriers that may prevent the patients from taking full advantage of the ePHR include patients' perceptions about privacy and security, inconvenience, and design shortcomings [44]. Other factors include patient low level of computer competency, health literacy, and Internet availability [44, 45]. The privacy is a crucial factor from the patients' perspective. One study found that 31% felt that their information was not confidential in the ePHR [46]. Another study conducted to understand the patient perceptions of the ePHR identified four themes about patient perceptions and barriers to the use of the PHR which include: access issues, perceived value of the

PHR, potential usability, and security issues as the most important factors may stand in the way of patients' adoption of ePHR [47]. Kim and Nahm conducted a literature review to identify the barriers to PHRs use among old adults. Their findings included the following factors as the barrier of use: data accuracy, privacy and security concerns, digital divide, and health and computer literacy issues [48]. Lober et al., 2006 studied the barriers of adoption and use of ePHR among the elderly population and categorized the barriers of adoption into access to PHR systems, access to computers, cognitive and physical disabilities, low computer or reading literacy, and low health literacy [49].

4.10 Physicians' and Nurses' Perspectives on ePHR

Physicians, nurses, and providers perspectives on the electronic personal health records are as important as understanding the patients' perspective and have been examined in different settings and with different health-care stakeholders. The attitude toward ePHR carries out with it different views of the adoption and use. There are attractive features and concerns regarding the ePHR for these distinct groups.

A qualitative study was conducted in 2011 to examine the Canadian physician's perspectives on the adoption and use of the ePHR [50]. It revealed that physicians are attracted to the features related to the ePHR portability and the ability to empower patients to engage effectively in their health care. In addition, some concerns were raised regarding data management, practice management problems, and changes to the patient-physician relationship [50]. Data management concerns include the security- and privacy-related issues. Some physicians may take a defensive position in the way they report the patients' medical information when the patients have full access to their health records as well as concerns about the data quality and accuracy when giving the patients the ability to enter health-related information into their health records [50]. However, some other studies showed that physicians have interest in giving the patients the ability to enter their health data and update their medication list in the portal and go over them with their physicians in the visits [51]. Concerns related to the patient-physician relationship may include the patient's ability to interpret and understand the medical terms and information stored in their accessible online records resulting in anxiety for the patients. Also, offering full access to the medical charts to the patients may be problematic especially in some psychiatric conditions [50]. Practice management problems are that with business-related implications such as the increase in the workload and time spent, and the fee-for-service business model may be affected because of the decrease in the face-to-face visits to the physicians' office [50]. However, if the health-care system is free as it is in some countries, then it would be very beneficial to decrease unnecessary face-to-face visits.

Another qualitative study was performed to study the health-care providers, nurses, and pharmacists' perspectives on the ePHR, My HealtheVet, at the

Department of Veterans Affairs (VA) revealed different views from these three groups [51]. The study showed that there are different views of the system among these three group because of their varying roles. Health-care providers showed concerns regarding the lack of workflow fit for such a tool to support patient self-reported information while emphasizing the improvement in the quality of the clinical visit because of the secure messages [51]. Nurses showed interest in the patients' motivation to adopt and use ePHR and highlighted the importance of giving the patients the ability to access information that they may need later [51]. Pharmacists, on the other hand, were concerned about the workload that may result since they believe that most of the secure messages are regarding prescription refills which they will have to fulfill [51]. These three groups showed different perspectives as their roles in the health-care process differ.

Interviews with 20 clinic personnel from health centers in four counties in the state of North Carolina were conducted to determine the administrators, clinic staff, and health-care providers views in the patient portals [52]. The study aimed to identify their perceived benefits and areas of concern. The findings of the study showed that clinic personnel believed that patient portals can improve the patient-provider communication, increase efficiency, enhance information sharing. Yet, some concerns were perceived such as the potential for the portal to add more workload, increase health disparities, privacy issues, and confuse the patients. Also, they believe that the adoption rate among the elderly population and disadvantaged patients would be low [52]. The main aspect of the increased efficiency benefits noted in the study is the volume of the received calls and how the portals can address this issue efficiently through the secure messaging feature. Nurses and physicians believe that answering a phone call to address a routine question or asking for a prescription refill may consume a time that other patients may really need it and it is easier and faster, for patients and clinic personnel, to communicate through electronic messages than through a phone call especially for the physicians who are not present in the clinic on a daily basis [52]. Also, clinic personnel expect an improvement in the patients' satisfaction and trust with their health-care providers as they observed from some cases of early adopters of the portal as they liked to have access to their health records [52]. Despite the great benefits that the clinic personnel think the ePHR would generate, they expressed three types of concerns: practice concerns such as ePHR may generate high volume of messages which would increase the workload, decreases in the office visits, and some liability issues; concerns related to the patients such as causing patient confusion or anxiety related to their level of health literacy as the physicians perceived, alienating older patients as nurses stated, and widening health disparities; and concerns related to the ePHR system which include inaccurate data entry, system failures or downtime, and security/privacy issues.

Family physician perceptions of the ePHR are key factors on the widespread and support of the ePHR adoption and use among the patients. In a study examining the family practice physician views on the ePHRs [42], physicians perceived many barriers for the patients' adoption of ePHR that may include patients' low levels of computer and health literacy, and low levels of patient interest and motivation to use the ePHR. The physicians' perceptions toward ePHR may limit or foster the patients' adoption as they play a significant role in the patients' intention to use ePHR.

Mixed methods, an electronic survey and focus group, were used to study the ePHR adoption and use at a large Midwestern academic medical center [53]. The aim of the study was to observe PHR use patterns, and detect physician's perspectives and role in encouraging PHR adoption. Physicians have a different perspective regarding the ePHR depending on the length of their experience in the practice. Physicians with more experience in the practice believe that they would spend more time interacting with the ePHR than the newer physicians. Consequently, ePHR activation rates for the more experienced physicians are lower. Also, physicians considered the lack of reimbursement for the time spent on using ePHR as a major obstacle in utilizing such a system. With that being said, the physicians believe ePHR would help their patients stay engaged with their health and more satisfied with their physicians as a result.

The physicians' intention to use the ePHR in certain health-care settings may require close investigation such as in the Emergency Departments (ED). ED physicians emphasized the importance of the speed of access to ePHR and they only showed interest in checking the ePHR of severely sick patients or patients with more than one health issue [54]. Majority of the patients, 96% of patients, in a study exploring the intention of the Patient and Physician to Use ePHR in the Emergency Department, expressed interest in having the ED physicians' access to their health information records in a life-threatening emergency [54].

Some studies have shown similar findings to the above. A study about the attitudes of primary care residents and faculty, at academic medical centers, toward the ePHR before and after its implementation showed that majority of the physicians who perceived and expected an increase in the workload before the implementation, had an opposite response after the implementation expressing no change to the workload [55]. Also, about half of the respondents expected an improvement in the quality of care before implementation; however, only one-third of them believed that the quality of care had improved after the implementation. Antoun, in 2016, showed that the use of e-mail as a communication channel between the patients and physicians still at a low rate. She showed that some physicians believe it would add more workload and some physicians are waiting for strong evidence to prove its effectiveness [56]. The same finding aligned with that of previous researchers from 2013 [57]. It showed that despite the effectiveness and efficiency of the patient-provider electronic communication, the increase in the workload was still perceived as a downside. There is still a debate in whether the secure messages between the patients and the health-care providers would cause more workload and time pressure.

Furthermore, health-care professionals propose some practical steps that may enhance the adoption and use of the ePHR rate [51]. Staff and patients should be educated about the ePHR features and functionalities and enabled with the hands-on experiences. This kind of education should lead the staff to better utilization of the portal and the available features and will encourage the patients to adopt and use them. Allow patients access to computers during their visits to get them learn more about the patient portal is another recommendation [51]. Also, ePHR should be integrated with the existing EHR, easy to use, and present the added value in the practice [50].

Besides the studies that looked at the physicians', nurses', and providers' perspectives on the ePHR, other studies looked at their intentions to adopt and use the ePHR as end users and the factors that influence their intention. A cross-sectional quantitative study from Taiwan investigated the factors affecting the intentions of nurses to adopt and use patient PHRs [58] found that the nurse's attitude toward ePHR adoption, directly, and subject norms, indirectly, influence the nurse's intention to adopt and use ePHRs. Factors such as perceived usefulness and computer self-efficacy significantly and positively affect their intentions toward ePHR adoption. This also aligns with the finding of a study [59], conducted to test the ePHR acceptance model by nurses adopting and using ePHR to manage their own health. It implies the importance of the EHR existence as a factor for the nurses to adopt and use ePHR since the nurses who work for providers that implemented EHRs had greater odds and chances of adopting and using ePHR than those working for providers who did not implement and use EHRs. The study also showed that older nurses who considered themselves as health-promoting role models had greater chances of adopting ePHR for managing their own health than younger nurses [59].

The literature review retrieved regarding the physicians, nurses, and providers perspectives on the electronic personal health records seemed to come from studies utilizing mostly a qualitative approach, specifically by interviews. It is important to understand the perspective of the physicians, nurses, and providers to better provide the patients with most adequate service.

4.11 Factor Influencing the Patient's Adoption of ePHR

There several factors play an essential role in the ePHR adoption. This section will address the most key factors influencing patient's adoption of ePHR such as health literacy, usability, computer literacy, health information exchange and interoperability, health-care provider's support, ePHR features, patient characteristics, and health conditions:

4.11.1 Health Literacy

Patient's health literacy is another factor that may prevent patients from taking full advantage of the ePHR. Patients may not have the interest to adopt and use a system that they find difficult to understand the information it consists. Health literacy is defined as "the degree to which individuals have the capacity to obtain, process, and understand basic health information and services needed to make appropriate health decisions." [60]. The low health literacy can add a financial burden on the health-care systems. Vernon et al., studied the health literacy implications on the national policy [61]. They stated that low health literacy costs the US health care system and economy between $106 billion and $238 billion annually. Health literacy also can be defined in terms of information technology as "the ability to read, use computers, search for information, understand health information, and put it into context" [62]. These two definitions emphasize the combination of the health information understanding and the information technology-associated commands. To measure the technology health literacy, Norman and Skinner have developed a reliable tool called eHealth Literacy Scale (eHEALS) to assess the patients' knowledge, comfort, and perceived skills in utilizing the information technology for the health issues [62]. Another study utilized "eHEALS" tool found out that patient's health literacy is a key factor in the patient willingness and interest to adopt ePHR [63]. It showed that 65% of the patients performed well in the health literacy scale which resulted in a higher interest in the ePHR adoption [63]. Health literacy is influenced by various factors such as education level, income, and age [63]. It is found that people with less education and having a low income are shown to be less likely to look up health-related information online [64]. Heuristic evaluation and usability testing are two assessment tools that can be used with an added focus to detect health literacy issues from the patient portal [65]. Low health literacy influences the patient perceptions toward the value of the ePHR as well [47]. In contrast, Cortelyou-Ward et al., [66] examined the patient engagement and patient-provider communication resulting from the use of ePHR to increase the patient health literacy which in return improved the patient satisfaction and outcomes. They suggest the importance of considering the ePHR as a tool that improves the patient health literacy and education. The health literacy positively influences the adoption of ePHR.

4.11.2 Usability

ePHR portal usability is an essential factor in the adoption. Usability of the patient portal means that the portal is easy to learn and use and simple to navigate [67]. There are some barriers to use that have been noted such as the ability to use and access to computers and Internet for some people especially [68] older adults. Usability evaluation on the health IT context can be a complex and costly process and depends on various factors such as number end-users or patients in the case of ePHR, the patient portal, and the process of the evaluation itself [69]. Usability of the patient portal or ePHR can be measured through heuristic evaluation or usability testing [65]. Heuristic evaluation is one assessment tool for ePHR that is conducted at low cost and has proved its success in identifying the challenges to use of such a system [69]. Heuristic evaluation depends on the specialists who evaluate and examine the portal to detect and note any issues that may influence its usability [65]. On the other hand, usability testing depends on the patients interacting with portal while the specialists observe the patients interaction and analyze and record any issues that the patients face [65]. The human-centered design method evolves around the patients and allows them to shape the design of the end version of the portal and improve its usability [67]. In this method, participant patients are asked to perform certain scenarios in the patient portal and think aloud as they proceed. They also complete surveys and conduct interviews thereafter. The results are then analyzed to present design improvements [67]. A study conducted to evaluate usability and usefulness of ePHR for older adults analyzed four components of the ePHR which are tasks, users, representations, and functions [70]. It was found that the tasks were easy for the patients to learn and apply even though the performance time appeared to be slow [70]. University of Victoria's eHealth Observatory has evaluated the Personal Health Portal (PHP) of Alberta Health facility in Canada focusing on the predesign, design, and adoption assessment using persona-based usability inspection combined with usability testing sessions. The study focused on the early usability assessment of the PHR application and found out that there is a great opportunity for improvement that can add tremendous value to users in different areas of the PHR information architecture, content, and presentation [71]. Overall, it is important to consider the patients in the process of designing the ePHR. Failure to do so may lead to human errors and difficulty to use which would lead to unsatisfied patients that may result in abandoning the system and slow rate of adoption.

4.11.3 Health Information Exchange (HIE) and Interoperability

Both Health Information Exchange (HIE) and interoperability involve the transfer of information either from one health-care provider or system to another. They pose a crucial role in the adoption and acceptance of the ePHR since they help in providing a full picture of the patient health record. It is important to mention and understand the difference between the HIE and interoperability as they involve the transfer of patient health information.

4.11.3.1 Health Information Exchange (HIE)

The HIE is perceived to have two definitions: one as a verb and the second as a noun. Healthcare Information and Management Systems Society (HIMSS) defines the verb HIE as "the sharing action between two or more non-affiliated organizations with an executed business/legal arrangement that have deployed commonly agreed-upon technology with applied standards for the purpose of electronically exchanging health-related data between the organizations" and the noun form of the HIE as "a catch-all phrase for the health information exchange organizations (HIOs) providing data exchange under the legal arrangements" [72]. It is important to mention the regional health information organization (RHIO) as an important element in the health information exchange process which is defined as "a type of health information exchange organization (HIO) that brings together health care stakeholders within a defined geographic area and governs health information exchange among them for the purpose of improving health and care in that community" [73]. Based on the HealthIT.gov, HIE "allows doctors, nurses, pharmacists, other health care providers and patients to appropriately access and securely share a patient's vital medical information electronically—improving the speed, quality, safety and cost of patient care" [74]. HIE aims at achieving the goals of improving health-care quality, enhanced workflow efficiency, and reduced cost [75]. Efficiency improvement includes being able to access test/lab results from other providers and improve the efficiency of the office administration workload regarding handlining referrals and claims processing [75]. The concerns related to HIE may include technical and organizational ability of the health provider, privacy and security, and cost concern [75]. There are three forms of HIE: Direct Exchange, Query-based Exchange, and Consumer Mediated Exchange [74]. The ONC works toward supporting governance initiatives of nationwide HIE to enhance interoperability, reduce the cost of information exchange, and increase trust among participant involved in the HIE process [76]. There have been many studies that have examined the ePHR and HIE. Patients and health providers express an interest in using ePHR for the purpose of accessing, sharing, and exchanging vital health information such as medical history and medication list [77] which would not be possible without the existence of HIE. Another study examined the patients' perceptions and attitudes toward PHR and HIE use by their health providers [78]. The study showed a great patient's interest in PHR to access their health information and concluded by emphasizing the importance of addressing the issues related to the privacy and security as part of HIE process. Patel et al., [79] examined the patient's support for HIE and PHR and concluded that patients support the physicians' use of HIE. It emphasized the importance of demonstrating the benefits of HIE to the underserved population in order to achieve a higher rate of HIE acceptance and support [79]. The HIE is an essential element of the ePHR success as it allows the exchange of patient health information across different health-care providers for the purpose of supporting and providing better health-care service.

4.11.3.2 Interoperability

The interoperability between the systems that deal with ePHR is essential success factor for the ePHR adoption. Healthcare Information and Management Systems Society (HIMSS) defines interoperability as the "the extent to which systems and devices can exchange data, and interpret that shared data." [80]. HHS and ONC annual progress reports submitted to the US Congress stated the importance of building interoperable health systems [81]. In order to build interoperable health system, HHS highlights the key priorities to provide seamless and secure flow of health information that include: propose standards to enable the seamless and secure exchange of health information, build business case for interoperability, and change the culture around access to health information. The activities involved in building the business case for interoperability in order to better assist the smooth information flow include: moving toward value-based care, Supporting Health Care Providers utilizing health IT by providing Technical Assistance and sufficient guidance and resources, and CMS Funding to foster the Electronic Health Information flow [81]. The ONC aims at changing the culture around access to health information by supporting the rights of patients to access their health information, efforts to discourage information blocking, and encouraging transparency as indicated in the annual report. It also emphasizes the interoperability commitments to ensure proper consumer access, transparency, and electronic health information standards implementation [81]. Archer et al. [82] conducted a literature review on the ePHR. They showed that having a functional ePHR relies on the existence of unified technical standards for the system interoperability [15, 82]. Interoperability is considered as a key factor in the successful ePHR adoption [15]. These standards required to have interoperable ePHR include security and privacy standards, adoption and use of certified HIT solutions, and data interchange standards [82].

HIMSS has formed a group of HIE and interoperability experts to prepare a comprehensive business case for the adoption of HIE and interoperability. The group has identified some challenges and barriers to HIE and interoperability adoption [72]. The cost associated with having such systems may include hardware, software, implementation and ongoing training, maintenance, and staffing [72]. Also, barriers identified in the report include lab data transmission standards, privacy and security, long-term care/behavioral health, semantic and syntactic interoperability, competing and conflicting document standards. The existence and success of HIE and interoperability in the health-care system allow for the successful exchange of essential health information and in return improve the chance of other systems such as EHR and ePHR success. The document as well presents the benefits of successful implementation of HIE attained by hospitals, physicians, patients and health information organizations such as improved and efficient workflow, faster and easier access to various health information, better decision making by having necessary data in hand, more patient involvement in their care, and reduction in health-care costs. The utilization of HIE and better interoperable systems resulted in, as per pilot study presented in the report, 53% drop in non-urgent visits to ER, 68% increase in primary care visits, and cost saving of between two and four million dollars over a period of 6 months.

4.11.4 Computer Competency

Patient's ability and knowledge to utilize computers have considerable influence on the adoption of health technologies. These factors include computer literacy, access to computer and Internet, Internet reliance deemed by certain technologies such as ePHR, computer anxiety, and personal IT innovativeness. Computer literacy requires the ability to have access to the computer and use it to solve a problem or accomplish certain task [83]. The relationship between the patient's computer knowledge and the adoption of the HIT has been investigated by many researchers. Saranto and Leino-Kilpi examined the computer literacy in nursing [84]. They used a three-round Delphi survey to extract knowledge from experts. The results showed that nurses are required to have computer knowledge and skills especially in accessing and using the hospital information system as well as be aware of the computer security threats and implications [84]. Computer literacy contributes to the ability of the patients to effectively adopt and use the ePHR [85]. In a study examining the barriers to the use of ePHR by an elderly population, computer literacy and computer anxiety were ranked as the top major barriers in using ePHR by elderly population [49]. Other computer-related barriers that limit the utilization of the ePHR are the patient's lack of computers and nurses' negative attitudes regarding computer usage [86]. Cocosila and Archer empirically investigated the patients' perceptions on the adoption of ePHR [87]. The study examined factors to predict the intention to adopt ePHR that include Internet reliance, computer self-efficacy, personal IT innovativeness, security and privacy and trust, anxiety, and perceived usefulness. The findings showed that personal IT innovativeness and perceived usefulness are the top factors influencing ePHR adoption. The findings also showed the positive impact on the adoption by the following factors: Internet reliance, security and privacy, and trust constructs. The access to the Internet and computer literacy is presenting the digital divide concept. The digital divide is described as "the gap that exists among individuals and communities with regards to the 'haves' and 'have-nots' of information and modern communications technologies" [88]. The digital divide represents the "disparities among subgroups based on access to the Internet and computer literacy" [5]. Digital divide is shown to be a problem facing the ePHR adoption and use [48]. Different technology adoption models have considered the computer-related factors to measure and predict the ePHR adoption. The TTF model study the how technology supports people accomplishing tasks by examining the following factors: technology characteristics, task characteristic, task-technology fit, performance impact, and utilization [89]. One of the Unified Theory of Acceptance and Use of Technology model four constructs, facilitating conditions, examined the degree to which an individual believes that resources and technical infrastructure exists to support the use of the ePHR [90]. In the context of health IT, computer literacy has generated and new concept call eHealth literacy. eHealth literacy is a concept that has been developed to combine the computer literacy and health literacy. It is defined with regard to the patients as "ability to seek, find, understand, and appraise health information from electronic sources and apply the knowledge gained to addressing or solving a health problem" [83]. It is also shown that there is a positive relationship between the health literacy and use of Internet-based technologies [64].

4.11.5 Health-Care Provider's Support

The support and encouragement of the health-care providers, physicians, nurses, and hospital administrators to the patient's adoption of the ePHR is crucial. A study about the patient portal and patient engagement showed the importance of the providers acceptance and promotion of the ePHR [5]. Studies show that there is an increasing attention from the clinical staff in educating and supporting patient to use and access the patient portals [23]. Another study examined the intentions of nurses to adopt patient's ePHR [58] suggests that subjective norms had the most significant influence on the attitudes and intentions of nurses to use ePHRs as they are influenced by their peers. It emphasizes the importance of nurse's contribution in the development and promotion of the ePHR as well. Nurses play key role in the ePHR introduction to the patients and as a promotion role model. Nurses can add insight into the development and revisions of the ePHR [47]. On the other hand, patients trust their physicians and are willing to follow their advice to adopt and use ePHR if they recommend it to them [87]. Vydra et al. [53] emphasized the importance of the physician endorsement for the ePHR to gain widespread diffusion. They highlighted the significance of rewarding the employee using ePHR the most, providing financial reimbursement for workload resulting from the time spent on the ePHR communicating with the patients and providing more ePHR educational materials. Satisfaction with health-care provider and the current medical care improve the chances of the patient adopting and using their provider's ePHR [87]. The ownership of the ePHR software appears to matter to the patients. A study was conducted to investigate the patient's and physician's willingness and interest to adopt and use ePHR in the emergency department [54]. The study showed that patients prefer the hospitals as the source of the ePHR and to control their health information rather than any other entities such as the software company, the government, and insurance company. The health-care entities should put more efforts in promoting the adoption and use of ePHR among patients. Wells et al., investigated the health-care provider's organizational strategies to promote the ePHR patient's adoption [91]. The study showed that raising patient awareness through multimedia communications about the existence and benefits of ePHR, and provider's acceptance are on the top priorities of the organizational strategies. It highlights the role of health professional encouragement and endorsement as a key effective strategy. Another study suggests that in order to promote the adoption of ePHR, policymakers should provide sufficient assistance in the forms of financial support, interoperability, and training of information technology support staff [92]. It is obvious that the role of health-care providers, physicians, and nurses on promoting the ePHR adoption and use is an important success factor toward the widespread of the ePHR adoption.

4.11.6 Health Condition

The health condition and ePHR adoption appear to have a positive correlation. Many researchers have examined the adoption and use of ePHR for chronic condition management. The health condition may play a factor in the ePHR adoption. Patients with chronic diseases tend to have higher adoption rate of the ePHR than patients without chronic diseases [23, 25]. According to the Connecting for Health report which is part of the Markle Foundation's [4], patients with chronic diseases tend to have a higher interest in the ePHR with a percentage of 65% compared to 58% of the patients without chronic diseases. Studies suggest the utilization of ePHR as a method to improve chronic disease self-management [2]. Irizarry et al. [5] showed that patients with chronic conditions and disabilities have a higher rate of adoption and use of the ePHR. Laugesen and Hassanein has developed a theoretical model for ePHR adoption by chronic disease patients as self-management tool [2]. The model intends to explain the health-related behaviors through the Protection Motivation Theory (PMT) and information technology adoption through Task Technology Fit (TTF) theory in combination with the health self-management readiness concept of the Patient Activation Measure (PAM). The new theoretical model was tested and validated via statistical model by surveying diabetes patients. The results of the model indicated that all constructs used in the models showed significant influence on the patient's intention to adopt an ePHR for the chronic condition management. A systematic review conducted in 2015 on 27 selected articles investigating the patient and provider attitudes toward the use of patient portals for the management of chronic diseases [40]. The study revealed substantial improvements in the patient with chronic disease self-management and the quality of care provided by the providers has enhanced. Also, there were positive and negative attitudes toward the patient portal. Patient-provider improved communication represents the positive attitude and the security concerns and user-friendliness were the negative attitudes noted [40]. ePHR has been used as health management tool for various health conditions such as diabetes, asthma, cancer, and for the children's health care. ePHR is used to help diabetes patients in better managing their health. A qualitative study is conducted to study the use of ePHR to improve diabetes management [93]. The study was intended to capture the perspective of the patients, general practitioners, nurses, diabetes educators, and clinical staff about the ePHR as an online diabetes management tool. The study identified four themes: disease management facilitators, challenges to ePHR use, the communication between the patients and providers, and ePHR system improvement recommendations. The results of the study showed that patients are more engaged in their care due to the ePHR as a management tool, and emphasize the role of the health-care providers as facilitators of disease management. ePHR also has been used in the primary care settings to manage chronically ill children. The ePHR adoption is investigated in the primary care setting, as well, as a management tool of pediatric asthma [94]. The study aims at exploring the results of potential improvement in the patient-provider communication due to the ePHR adoption and use of the clinical outcomes. The findings suggest that patients with uncontrolled asthma appeared to have more medication changes and clinic visits after starting to use the ePHR compared to the year earlier. It noted that the adoption rate is unlikely to be achieved in the short term and the more efforts are required in the ePHR implementation phase [94]. Pai et al. conducted a study to capture feedback from prostate cancer patients who were given an access to an ePHR in order for them to view their medical records and use a set of support tools [95]. Information about usability, satisfaction, and concerns with the ePHR were gathered. The findings showed that the most used functions were test results and transcribed doctor's notes. Prostate cancer patients in the study showed positive responses regarding the use of ePHR with high satisfaction rate, being able to find answers to their questions, and privacy was preserved. They also agreed that the ePHR had improved their communication with their physicians and would continue to use it in the future. Clark et al. have explored the current ePHR adoption by parent's as caregivers to manage their children's health care [96]. The study aimed at capturing the parents perspective and have found out that the main reason for the parent's chose not to use ePHR to manage their children's health care is the low perceived need to do so. It also showed that the most used functions of the ePHR for the parent's adopting ePHR are checking lab results and immunization records.

4.11.7 Portal's Features

The ePHR features and functionalities have a positive influence on ePHR adoption. Patients want to have more control over their records and be able to explore a wide range of the portal's features. In some cases, patients use the ePHR because they like certain features that they use frequently. A study found that the features of the ePHR that patients use most frequently include checking their lab results, being informed of health changes, and managing chronic disease [97]. The Foundation for Accountability (FACCT), as part of the Markle Foundation's Connecting for Health program, studied the ePHR functionalities and their usability by surveying 1246 online individuals between 2002 and 2003 [4]. The features of the ePHR that were tested are: messaging doctors, checking immunizations, noting mistakes in one's record, transferring information to new provider, and testing results. The findings showed that over 70% of respondents have interest in using one or more features of the PHR, 35% would use seven or more features if it were available, 75% use ePHR to communicate with doctors through e-mail, 69% to track immunizations, 69% to track mistakes in their records, 65% to transfer information to new health-care provider, and 63% to check the test results. The more features and functionalities offered to the patient through the ePHR, the more interested and engaged they are.

4.11.8 Patient Characteristics

Current research has demonstrated that patients' interest and ability to use ePHR is strongly influenced by personal factors such age, ethnicity, education level, health literacy, health status, and role as a caregiver [5]. Health-care delivery factors, mainly provider endorsement and patient portal usability, also contribute to patients' ability to engage through and with the ePHR [5]. A study examining the digital divide in the adoption and use of ePHR investigated the characteristics of the ePHR adopters and nonadopters based on the activation of the ePHR online account given by their health providers and the frequent use [98]. The study showed that the percentage of patients adopting ePHR is 43% out of 75,056 patients representing the population of the patients in a certain health-care facility. The study indicated that the adoption and use of ePHR among certain populations such as the underserved, low-income, and elderly seem to be low due to factors like lack of access to computer or Internet and the fear of using such a computerized system. The study showed that the white population has a higher rate of ePHR adoption compared to blacks and Hispanics as the race could be used as a determinant of adoption. Also, people with higher income appeared to have higher adoption rate than people with lower income. The paper concluded with the statement that the following factors: increasing number of chronic diseases, race/ethnicity, and insurance status are used to predict the intensity of the ePHR usage. Another study indicated that there is a low rate of adoption by the race and ethnicity. It is as well shown that might be a result of either the lack of interest and motivation in such a system [23] or the availability of the computer and Internet connection [99]. Elderly population as potential ePHR adopters are an important segment of the ePHR adoption and use. A study investigated the older adult's perspective on the adoption and use of ePHR interviewed 74 elderlies to capture their perspective [100]. The finding showed that only 20% reported using ePHR. The interviewee cited the most valuable features of the ePHR as the ease of access to health records and direct messaging and communication with health providers. The study highlighted the lack of computer proficiency, Internet costs and security concerns as the barriers to adoption by elderly. It indicates the importance taking into consideration the elderly perspective when designing and implementing ePHR. Sakaguchi-Tang et al., conducted a systematic review to study ePHR use and experience among older adults [68]. The review identified two barriers: privacy and security concerns and lack of competency to use technology. The study highlighted two facilitators: technical assistance availability and family and provider advice. Czaja et al. studied the use of ePHR by underserved adult population to perform health management activities [101]. The results showed that older adults consider the ePHR as a valuable tool despite not being able to complete certain tasks and needed assistance. It can be concluded that the race/ethnicity, income, and age factors influence the adoption and use of ePHR. Barriers that should be considered in designing the ePHR and influence the adoption include the lack of computer and Internet access, the fear to deal with technology or perform certain ePHR tasks, and the need for assistance.

4.11.9 Perceived Credibility (Privacy and Security)

Privacy and security of the health information can pose a huge threat to the ePHR adoption. A study found out that about 91% of the patients are very concerned regarding their health information being secure and safe despite their belief that ePHR systems are safe and their health information is protected [4]. In the case of the chronically ill patients, patients value some of ePHR features over the privacy and security and feel less concerned about their health information privacy [4]. Dontje et al. ranked the security issue as one of the barriers of ePHR adoption factors [47]. Ong et al. added a new construct to the TAM called perceived credibility to test the consumer's acceptance of a certain technology [102]. Perceived credibility is defined with regards to the ePHR as the degree to which a person believed that using ePHR would be free of privacy and security threats [102]. A survey-based study was conducted to investigate the factors that motivate nurses to protect the privacy of electronic medical records (EMR) [103]. The findings suggest that the factors of attitude, subjective norm, and perceived behavioral control of the nurses significantly predicted the nurses' intention to protect the privacy of EMR. The privacy and security of the ePHR are essential factors influencing the patient's adoption of the ePHR.

4.12 Sample ePHR Application (My HealtheVet)

This section examines one of the earliest developed and implemented ePHR applications that enables patients access to their health records. My HealtheVet was introduced by the US Veterans Health Administration as an electronic personal health record in 2003. My HealtheVet enables Veterans to access and manage their VA health records online. They can track their test results and record health history. The numbers show an increasing attention from the US Veterans to adopt and use My HealtheVet as the number of registered users reached 850,000 as of October 2009 which represents around 16% of the total VA patients receiving service [104]. The number of visits to My HealtheVet website since it was launched in 2003 reached 32 million visits [104]. The prescription refills were one of the top used features of My HealtheVet as the number of refilled prescriptions exceeded 11 million prescriptions from 2005 to 2010 [104]. The components of My MealtheVet include: Personal Information, Pharmacy, Research Health, Get Care, Track Health, MHV Community, Wellness Reminders, Secure Messaging, and VA Blue Button: Download My Data [105]. Main webpage of My HealtheVet, (https://www.myhealth.va.gov/), has four main features: pharmacy, appointment, messages, and health records [106]:

My HealtheVet has been examined by researchers as it is the one of the first to develop ePHR. A qualitative study examined the patient experiences and opinions with full electronic access to health records and clinical notes through the "My

HealtheVet" ePHR [107]. The findings showed that patients with the ability to access and look up their health records felt their communication with their providers was positively influenced, their knowledge about their care improved, and they felt they were more engaged in their care.

Nazi et al. evaluated the patient access to EHR from My HealtheVet ePHR [108]. The study showed that patients were satisfied with the ability to access their health information and agreed that the information was helpful and beneficial. It showed that the most frequently used feature was the access to ePHR from the VA EHR. Another study showed similar findings as they stated that veterans expressed very high satisfaction rate with My HealtheVet and they were likely to visit the site again and to recommend it to other veterans [104].

Another study conducted a cross-sectional analysis to investigate how patient's health status may affect the adoption and use of the ePHR [109]. The study suggests that patients with chronic disease such HIV, hyperlipidemia, and spinal cord injury tends to have the highest predicted probabilities of the ePHR adoption. The study highlights the importance of increasing the adoption rate especially for the patients with health conditions that may require special treatment and self-management as there is an opportunity for My HealtheVet to support.

4.13 Global ePHR Attention

There has been noticeable attention from countries all over the world toward health information technology. They seek to utilize the information technology to advance their health care systems and provide better quality of care to their citizens. This section aims at investigating the efforts and the current ePHR adoption rates in the Saudi Arabia and the US.

4.13.1 Adoption of Health IT in Saudi Arabia

In the recent years, the health IT has gotten much attention and interest by the Saudi Arabian Ministry of Health and by recognizable health-care providers. Most of the hospitals in Saudi Arabia are owned, operated, and funded by the Saudi Arabian Ministry of Health. The rest of the hospital are private hospital, university hospital, and medical cities. The Saudi Arabian Ministry of Health. The Ministry of Health has struggled in the past to keep up the advances in the health IT as a result of the high associated cost and the lack of information and communication infrastructure in its hospitals scattered over the country [110]. However, the Ministry of Health launched an initiative to build central national database for the implementation of the EHR. The aim was to link all hospitals and ensure a national EHR [110]. The other category of hospitals such as the Ministry of National Guard, Armed Forces, Security Forces hospitals have made great progress in implementing health IT solutions, EHR, and patient's engagement systems [110]. The health-care services provided by the Ministry of Health is offered to the citizens for free of charge and the most funds are directed toward building new health facilities and covering the health-care costs which in return made it harder in the past for the Ministry of Health to invest in costly health IT solutions. However, in the recent years the attention paid by all health care-providers including Ministry of Health toward health IT is way better than it used to be.

The research publications examining the adoption and use of the health IT is still low. A study conducted to review the current literature about the E-Health status in Saudi Arabia showed the growing attention paid to E-Health. It showed also that the number of publications regarding health IT remains low [111]. El Mahalli examined the adoption and barriers to the use of an EHR system by nurses at three governmental hospitals [112]. The study findings showed underutilization of almost all functionalities and features of the EHR in all hospitals. Also, the study revealed no utilization of any communication tools with patients. The top barriers cited in the study include lack of technical training/support, increased workload, and system hanging up/downtime issue. Khudair investigated the Saudi physicians' perspective toward EHR [113]. The results showed that physicians emphasized the importance of accurate data organizations and archiving files. Also, physicians perceived the reasons behind the slow adoption of EHR by hospitals to the slow actions taken by the top management. However, IT managers perceived the physicians' readiness as a key success factor in the EHR implementation. Al-Sahan and Saddik examined the perceived challenges for adopting the ePHR at Ministry of National Guard Health Affairs (MNGHA) in Saudi Arabia from technical and social perspectives [114]. The study utilized two approaches: it measured the patients' perceptions of the ePHR using a questionnaire and focus groups to capture technical personnel comments and perceptions. The study highlighted positive patient perceptions toward ePHR adoption. Patients, in the study, did not indicate concerns regarding the confidentiality of their health information due to the online access. One major barrier was presented by the patients was the lack of awareness of the existence of ePHR. On the other side, the technical personnel expressed the importance of the policies and regulations for the ePRH adoption. Alsanea demonstrated the future of health-care delivery and the experience of a tertiary care center in Saudi Arabia [115]. He identified five technological advancements that would change the health-care delivery as digitalization of the PHR and data sharing, increased accessibility through "Online Patient Services," preventive medicine revisited, online patient education, and smart applications as counselors. He presents the King Faisal Specialist Hospital and Research Centre (KFSHRC), one of the most recognizable health-care facilities in Saudi Arabia, experience in utilizing EHR and ePHR. KFSHRC launched "Online Patient Services" with the patients being able to access the following menu lists: appointments, social services, patient relation services, medical reports, biographic data, medications and authentication of medical leaves with sub-services under each menu list. The expected benefits of the new system are significant. The new "Online Patient Services" was expected to reduce the number of unnecessary visits to the hospital significantly. He estimated that number of visits to the hospital is 5000 visits per day to perform one of the following services: appointment rescheduling, request of medical reports, and refill of medications. These services can be done online and if they were to be completed through the online patient service, that would result in a major drop in hospital car traffic. This reduction in the number of visits would improve the hospital efficiency hospital traffic and expenditure associated with patients travel expenses and accommodations as well as direct the hospital's resources to treat more patients. The online patient service had very good acceptance by the patients as the number of online visits reached 1,100,000 visits for 450,000 active users. Unfortunately, the number of publications examining the adoption and use of ePHR is very limited in Saudi Arabia due to the fact that it is very new technology and only a few health-care facilities offer such a service to their patients. More studies are required to address the factor influencing the adoption and use of ePHR.

4.13.2 US Initiatives and Programs Toward Health IT Adoption

This section introduces the USA as a global leader in the field of health information technology, and efforts and initiatives that facilitate and contribute toward the adoption of the Health Information Technology and specifically the Electronic Personal Health Records (ePHR). There have been many organizations and agencies that contributed to the development, setting up regulations, proposing policies, giving incentives, and conducting research studies regarding the electronic personal health records such as the Department of Health and Human Services (HHS), The Office of the National Coordinator (ONC), American Health Information Management Association (AHIMA), the Center for Medicare and Medicaid Services, Healthcare Information and Management Systems Society (HIMSS), and many other concerned groups and associations. The following sections will highlight some of their efforts in supporting the ePHR adoption. This section introduces the most influential efforts that influence the ePHR adoption.

4.13.2.1 The American Recovery and Reinvestment Act of 2009 (ARRA)

The Healthcare Information and Management Systems Society (HIMSS) provided a summary of the American Recovery and Reinvestment Act of 2009 (ARRA) focusing on the health information technology related funds [17]. The ARRA goal is to incentivize the economy through investments in different sectors. The Healthcare IT sector was aided by over $20 billion to support the development of health IT infrastructure and to encourage involved parties to adopt and use health IT. The ARRA Act considers the EHR and PHR as significant elements of the national policy aiming at achieving the goals of improving the quality of care, safety, efficiency, and reducing costs. The following is some of the initiatives and programs that were funded as part of the health IT aid:

- $20.819 billion were assigned to the center for Medicare and Medicaid (CMC) to support its incentive programs that aims to assist health-care providers in adopting EHR.
- $1.5 billion to support construction, renovation, and equipment for health centers.
- $50 million for information technology within the Veterans Benefits Administration.

The ARRA proposed The Health Information Technology for Economic and Clinical Health act (HITECH).

4.13.2.2 The Health Information Technology for Economic and Clinical Health (HITECH) Act

The act was signed into law on February 17, 2009, as part of the American Recovery and Reinvestment Act (ARRA) of 2009. The goal of the act is to endorse the adoption and meaningful use of health IT especially the electronic health records [116]. HITECH act also aligns with Health Insurance Portability and Accountability Act (HIPAA) in addressing the privacy and security issues linked to the electronic transmission of health information [116]. The HITECH proposed policies to foster the adoption of the Electronic Health Records which is the core base of the tethered Electronic Personal Health Records and protect the patient health information [117]. In terms of the direct influence of the HITECH act to ePHR, the existing provisions involve the electronic exchange of the patient's records that would require a great attention to the tasks related to the interoperability and privacy requirements for PHRs [117]. The act requires an establishment of an Office of the National Coordinator for Health Information Technology within the Department of Health and Human Services to ensure the electronic exchange of health information meets the HIT standards, sustain the Federal health IT Strategic Plan, and etc. [118].

4.13.2.3 Office of the National Coordinator for Health Information Technology (ONC)

ONC was established as part of the HITECH and dedicated to supporting the nationwide adoption of health information technology, assess the impact of the HIT in all levels of the communities, identify new ways to foster the adoption of HIT, and evaluate the benefits and barriers of the HIT adoption [118]. The 2018 budget estimation report of the Office of the National Coordinator for Health Information Technology (ONC) presents two key priorities: increase the usability of the EHR and interoperability of health information [1]. Based on the report, ONC's policies brought significant impact on the HIT adoption rate. The ONC provides incentives to providers that implement certified electronic health records which have fostered the adoption rate [1]. The report indicated, as a result of the (ONC) efforts in supporting the HIT adoption, an increase in the number of office-based physicians' adopting EHR from 17% in 2008 to 58% as of 2015. Similarly, it showed that the nonfederal acute care hospitals with certified EHR rate increased from 9% in 2008 to 84% as of 2015.

4.13.2.4 The Health Insurance Portability and Accountability Act of 1996 (HIPAA)

The Health Insurance Portability and Accountability Act of 1996 (HIPAA) aims at developing regulations and policies to protect the privacy and security of the health information. The US Department of Health and Human Services (HHS) developed HIPAA privacy and security standards and rules. These standards aim at protecting health information and ensure secure transmission of the electronic transferred health information. These rules allow health-care providers to adopt and implement new innovative technologies to improve the quality of provided care while ensuring the privacy and security of the patient's health information. It also allows smooth and secure transmission of electronic health information between the involved parties such as health-care providers, insurance companies, and between the systems within the health-care facilities [119]. Privacy and security are a requirement of an interoperable health system and ensures, under HIPAA act, that the electronically shared health information is safe and secure by adjusting the perception of the industry about HIPAA by presenting how HIPAA regulations support safe information flow [1]. In regard to the ePHR, it falls under the HIPAA privacy and security policies to support the main goal of HIT adoption and allow secure patients engagement in their health by utilizing such a system [117]. The 2016 annual ONC report to Congress stated the patient access rights under HIPPA act that include the following: the patient has the right to obtain copies of their health information including information regarding their medical history, images, laboratory/tests results, and physician diagnoses and notes [81]. Privacy and security play a significant role in supporting the national HIT initiatives.

4.13.2.5 Center for Medicare and Medicaid Services (CMS)

In 1965, the Medicare and Medicaid programs were launched [120]. The CMS's goal is to support the Nation's health-care system in order to provide a high quality of care at a lower cost [121]. CMS proposed incentives program called "meaningful use" to support the health-care providers, office- and hospital-based, to adopt certified EHR [122]. CMS's measures "track the percentage of physicians, nurse practitioners, physician assistants, short-term general, Critical Access, and Children's hospitals that have demonstrated meaningful use of certified electronic health record technology and/or adopted, implemented, or upgraded any electronic health record". CMS also tracks the rate of adoption by providers [122]. The meaningful use consists of three stages and the providers should meet certain criteria for each stage to qualify for the incentives.

4.13.2.6 The Meaningful Use Program

The meaningful use started as a result of the ARRA act that authorized the CMS to provide incentive payments to health-care providers who "adopt, implement, upgrade, or demonstrate meaningful use of certified electronic health record (EHR) technology" [123]. The meaningful use goal is to widespread the adoption of certified EHR to achieve the following objectives [124]:

- Improve quality, safety, efficiency, and reduce health disparities
- Provide patient-centered health care by engaging patients in their health care
- Improve population and public health
- Maintaining privacy and security of the health information

The incentive program consists of three stages [125]: stage 1: aims to set the requirement for the electronic capture of the health data as well as give the patients the ability to digitally access their health information; stage 2: aims at advancing clinical processes and support the use of certified electronic health record (EHR) technology to improve the quality of care; stage 3: focuses on certified electronic health record (EHR) technology to improve clinical outcomes. Each stage has certain criteria that the health-care providers must meet to receive the incentive payments. The incentive criteria and measurements emphasize the importance of giving the patients access to their health records and engage them with their providers. Secure messaging is an important feature of the PHR that meets one of the objectives of the meaningful use stages 2 and 3 [23]. The meaningful use stage 2 requires that 5% of the health-care provider patients' population use secure e-messaging in order to qualify for the meaningful use stage 2 incentives [24]. The meaningful use patient portal-related features include the following as well: summary of each patient visit to the doctor, allowing secure communication between the patient and the health-care provider through the messaging feature, allowing the patient to view, download, transmit their health-related data, provide customized educational materials, patient reminders for preventative services, and medication reconciliation [126]. Also, as part of the meaningful use stage 1, the health-care provider must provide the patients the ability to view, download, and transmit their health information [127]. As well, meaningful use stage 2 requires the provider to communicate with patients through the portal. Giving the patients the ability to access their information is measured as the following: more than 50% of the patients are to be given online access to their records, and 5% or more view, download, and transmit their information [127]. ePHR is an essential element of the meaningful use.

4.13.2.7 Health IT Strategic Plan Report Submitted to the Congress

In the continuous effort to improve the health IT adoption in the USA, the US Department of Health and Human Services (HHS) represented by the Office of the National Coordinator for Health Information Technology (ONC) submits an annual progress reports to the Congress pursuant to Section 3001(c)(6) of the Public Health Service Act and section 13113(a) of the HITECH Act [81]. The latest report released in November 2016 is entitled with "Examining the HITECH Era and the Future of Health IT" [81]. The report highlights very essential health IT efforts such as demonstrating the current state of the health IT adoption, the roadmap to an interoperable Health System, and the critical actions to evolve health IT Use and Information. The report demonstrated the results of HITECH initiatives undertaken to foster the health IT adoption by providing adoption statistics. The statistics show a dramatic increase in the adoption of certified EHR technology among office-based physicians and hospitals between 2008 and 2015. For example, the percentage of hospitals with certified EHR jumped from 9% in 2008 to 96% in 2015. The report emphasizes the role of clinicians, hospitals, technologists, and patient collaboration and the financial incentives provided by the Centers for Medicare and Medicare Services that led to the health system digitization. The HITECH initiatives result in an increase in the use of functionalities that have clinical impacts and improved provider-to-provider and provider-to-patient communication. In order to build an interoperable health system, HHS highlights the key priorities to provide a seamless and secure flow of health information that includes proposing standards to enable a seamless and secure exchange of health information, building a business case for interoperability, and changing the culture around access to health information. The activities involved in building the business case for interoperability in order to better assist the smooth information flow include moving toward value-based care, supporting health-care providers utilizing health IT by providing technical assistance and sufficient guidance and resources, and CMS funding to foster the electronic health information flow [81]. The ONC aims at changing the culture around access to health information by supporting the rights of patients to access their health information, making efforts to discourage information blocking, and encouraging transparency as indicated in the annual report. It also emphasizes the interoperability commitments to ensure proper consumer access, transparency, and electronic health information standards implementation. In order to move forward in advancing the meaningful use of the health IT, the Office of the National Coordinator for Health Information Technology (ONC) initiated a Federal Health IT Strategic Plan 2015–2020 [128]. The strategic plan highlights four essential goals to be achieved by effective use of technology and information: enhance patient-centered and self-managed health; improve health-care delivery; support health IT innovation, knowledge, and research; and develop the health IT infrastructure.

4.14 ePHR Adoption and Use Models

Health Information Technology has been examined by theories and models from various areas such as technology, information system, health, human behaviors, social science, and phycology. This section will go through the essential models that have been used to investigate the adoption and use of the ePHR from the patient's perspective:

4.14.1 Theory of Reasoned Action (TRA)

The Theory of Reasoned Action is originated from the social science field. Its considered as one of the most notable theories in the human behavior that explains user's behavior [129]. The core constructs of the TRA are attitude toward behavior which is defined as "an individual's positive or negative feelings (evaluative affect) about performing the target behavior" and subjective norms "person's perception that most people who are important to him think he should or should not perform the behavior in question" [130]. The TRA assumes that the individual's attitude and subjective norm determine and influence the individual's behavioral intention which inconsequence dictate the individual's performance [131]. The TRA has served as a base for newly developed models such as the TAM [132] the Theory of Planned Behaviors (TPB) [133] and the Unified Theory of Acceptance and Use of Technology (UTAUT) [90]. The following Fig. 4.1 depicts the TRA [131]:

4.14.2 The Technology Acceptance Model (TAM)

The Technology Acceptance Model relies on two factors: Perceived Usefulness and Perceived Ease of Use, which are used to predict the patients' behavior toward accepting new technology such as the ePHR [134]. The TAM is an adaptation from the Theory of Reasoned Action (TRA) model [135]. The Perceived Usefulness is

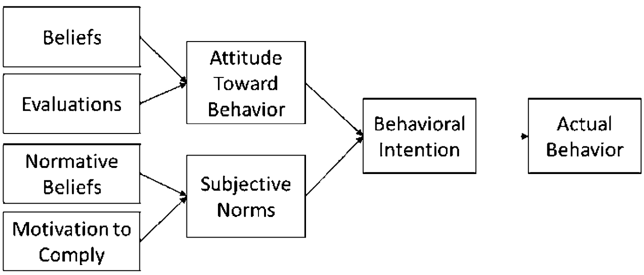

Fig. 4.1 Theory of reasoned action [131]

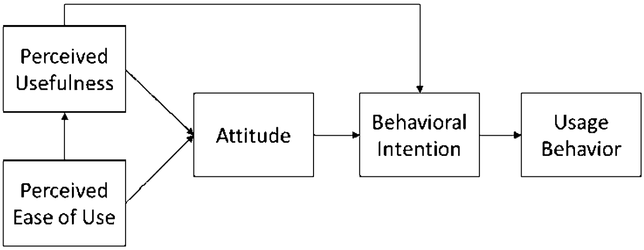

Fig. 4.2 Technology acceptance model [129]

defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" and the Perceived Ease of Use as "the degree to which a person believes that using a particular system would be free of effort" [134]. In the TAM, the attitude toward using ePHR and the direct and indirect influence of Perceived Usefulness and Perceived Ease of Use determine the intention of the patients to use the ePHR as depicted in the following Fig. 4.2 [129]:

TAM is considered as one of the most widely used models among researchers on examining an individual's acceptance of information systems as a very high number of articles using TAM has been published in leading information systems (IS) journals and conferences [136]. It is also found that TAM proved its ability to predict the systems, in the field of information technology, usage intention better than the Theory of Reasoned Action (TRA) when compared against each other [131]. Despite the high level of TAM model utilization among the researchers, there have been noted limitations of the TAM which include [136] TAM records the self-reported usage versus the actual usage and the difficulty to generalize the findings due to tendency of the model to test one information system on a single task in a specific period of time with a consistent group of subjects.

TAM has been used in the health area to test the usefulness and ease of use of certain health technologies such as the EHR or ePHR. Some researchers use the TAM with modification for the study purpose such as adding certain factors or constructs.

A study conducted to examine the technology acceptance model in the health care by reviewing 20 studies of clinicians using health IT for patient care found that the TAM showed to predict a significant portion of the acceptance or use of health IT; however, the model may benefit from adding new variables of modifying the models to better predict the user acceptance of certain technology [136]. Other studies used TAM added new factors to the model in order for a better understanding of the user's intention to use the technology. A study examined the ePHR acceptance by nurses for managing their own health added perceived data privacy and security protection; perceived health-promotion role, and moderator variables: age, chronic illness and medication use, and providers' use of electronic health records (EHRs) to the model as they are important in describing the nurse's intention in using ePHR [59]. Yarbrough [137] proposed an enhanced TAM model to study the technology acceptance among physicians. The new model suggests adding physician barriers to

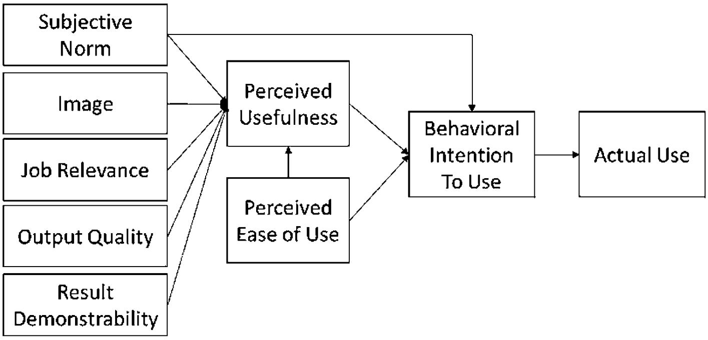

Fig. 4.3 Technology acceptance model "2" [136]

technology as a new variable. The new variable will directly influence the physician's intention to accept technology and indirectly will influence the technology acceptance through the TAM existing variables: perceived usefulness, perceived ease of use, and the attitudinal construct. The new model aims at improving the capability of the TAM by enhancing the understanding of the technology acceptance among physicians.

A new version of the TAM, called TAM2, has been developed by adding subjective norms construct to capture the social influence as a new predictor of intention to technology acceptance [138]. Subjective norms are defined as a "person's perception that most people who are important to him think he should or should not perform the behavior in question" [130]. The following Fig. 4.3 shows the depiction of TAM2 [136]:

4.14.3 Theory of Planned Behavior (TPB)

The Theory of Planned Behavior (TPB) is an extended model from the Theory of Reasoned Action (TRA) and is originated from the psychology field [133]. The TPB introduces a new construct, perceived behavioral control, to the TRA to better understand the individual's intentions to perform certain behavior or adopt a new technology. The TPB tries to understand the relationship between the intention and behavior by studying the factors that influence the individual's intention to perform or reject certain action [139]. Ajzen stated that in order to predict a behavior, intentions: must be measured prior performing the behavior and behavior should be under individual's volitional control [139]. The TPB emphasizes three factors that determine the intention to perform an action which includes attitude toward behavior, subjective norms, and perceived behavioral control. The intentions can be predicted with high accuracy from these three factors together and the combination of the intentions and the perceived behavioral control account for substantial variance in the actual behavior [133]. Perceived behavioral control as the new variable is defined as “the perceived ease or difficulty of performing the behavior and it is assumed to reflect past experience as well as anticipated impediments and obstacles” [133]. Factors such as the availability of skills, resources, and opportunities and their relative importance in performing certain action determine the perceived behavioral control [135]. Additionally, the performance of a certain behavioral depends on the intention; which is influenced by the attitude toward behavior, subjective norms, and perceived behavioral control; to perform that action and the ability or the behavioral control of the individual [133]. The intentions and perceived behavioral control can be used directly to predict the actual behavior. The three models: TRA, TAM, and TPB provide a great foundation for understanding some issues related to technology adoption and acceptance [135]. Taylor and Todd studied the three models in various applications of information system to understand the information technology usage [129]. The study concluded that a decomposed Theory of Planned Behavior, consisting of factors from both models: TAM and TPB, is shown to be the best model in understanding the information technology usage even though all the models were tested performed well in explaining the behavior. It also indicated that decomposed Theory of Planned Behavior showed to provide better understanding of behavioral intention by considering the factors that are assumed to influence the system use. Mathieson studied the TAM and TPB as they predicted the intention of the individual to use information system [140]. Mathieson found out that both models are sufficient in predicting the intention toward using IS. The study indicated that TPB provides specific information, measuring the system’s performance, and propose the barrier to system use factors while TAM provides general information on the individual’s views of the system in terms of ease of use and usefulness [140]. In the health IT area, Hsieh studied physicians’ intention to adopt and accept electronic medical records (EMR) exchange [141]. She developed an extended model of the decomposed TPB by adding two new constructs: institutional trust and perceived risk. Her findings suggest that perceived behavioral control factor has the strongest effect on the physician’s intention to use the EMR even though all the factors considered in the model showed significant effects. Another research, [103], studied the factors that motivate nurses to protect the privacy of EMR. The study utilized the Decomposed Theory of Planned Behavior to find out the factors influencing the nurse’s intention. The study concluded that all factors had significant effect on the nurse’s intention to protect the privacy of EMR except one construct, the perceived ease of protection, which had no influence on nurses’ intention. The patient intention to use health technology is essential and has been examined by utilizing the TPB. A study used TPB to predict patient’s intention toward accessing the after-visit summary (AVS) provided by the health-care provider through patient portal found out that attitude, perceived subjective norms, and perceived behavioral control account for about 57% of the variance in patient’s intention to access the after-visit summary [142]. Finally, the intention to adopt personal health records among nurses was examined using TAM and TPB while adding a new construct, perceived credibility [58]. In the study, perceived credibility means that using PHR is assumed to be free of privacy and security issues. The findings of the study suggest that perceived subjective norms showed to have the strongest effects on the nurse’s

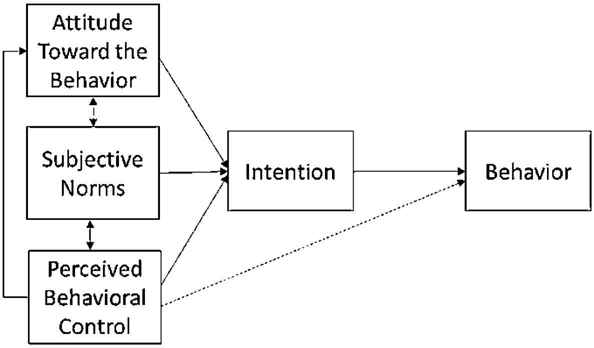

Fig. 4.4 The theory of planned behavior [133]

attitudes toward PHR adoption and in consequence have the greatest effects on the intentions to use PHRs.

The following Fig. 4.4 represents the TPB [133]:

4.14.4 Task Technology Fit (TTF)

Goodhue and Thompson in 1995 developed the Technology Task Fit (TTF) to help understand the impact of information technology on individual's performance [89]. To ensure that technology improves the individual's performance, technology must be used and be a good fit with the task it is used for [89]. The TTF is defined as "the degree to which a technology assists an individual in performing his or her portfolio of tasks" [89]. TTF consists of five elements: technology characteristics, task characteristic, task-technology fit, performance impact, and utilization [89]. Goodhue and Thompson found a moderate support for the assumption that Task and Technology Characteristics Predict TTF. They also found strong evidence that in order to predict performance impacts, TTF and utilization should be included in the evaluation. The Technology Task Fit has been used in many areas such as learning management system [143], supporting software maintenance [144], mobile information system [145], and most importantly to this study in the health information technology [146–150]. Laugesen utilized TTF, Protection Motivation Theory (PMT), and the concept of Patient Activation Measure (PAM) to study the adoption of ePHR by chronic disease patients [146]. He found that TTF proved its ability to explain the patient's intention to adopt ePHR. A study investigated the hospitals' computed tomography patient-referral mechanism by applying the TTF model in order to understand the relationship between the information system and task performance [147]. The findings indicated a strong relationship and should result in higher hospital performance, reduced patient wait time, and improved quality of health care for patients. Lin [148] as well applied the TTF to examine how the mobile nursing IS helps nurses perform daily clinical work as another application of TTF and test the organization readiness. The findings showed that technology-individual fit, task-technology fit, and organization readiness impact the system usage with the former being the most significant usage influencer. The study proposed mobile nursing information systems implementation and organizational recommendations such as: the system should be easy to use and learn, be portable, as well as, the importance of the top management support and the willingness of the nurses to utilize the system. Cady and Finkelstein [149] studied the usage of the video telehealth to provide care between clinic visits in a pediatric outpatient clinic using TTF framework. It showed that video telehealth provided a better visual information needed to support greater diagnostic information. Finally, TTF is used to study the user's assessment of the EHR system and its influence on the user's performance [150]. The study indicated positive assessments of the user's evaluations of the TTF elements. It stated the ease of use and training, and data quality as most important influencers of the performance impact. Overall, Technology Task Fit has been utilized across the health sector to examine the relationship between the health information systems and the task performance. It has provided a better view of the relationship and in identifying areas of improvements. It is as well considered as a great tool to explain the user's intention to use health IT.

4.14.5 Unified Theory of Acceptance and Use of Technology (UTAUT)

In 2003, Venkatesh et al. introduced the Unified Theory of Acceptance and Use of Technology to study the user's intention and behavior toward technology acceptance and use [90]. The construction of the UTAUT is based on a review of several essential acceptance models: TRA, TAM, motivational model (MM), TPB, Model of PC utilization, Innovation Diffusion Theory (IDT), and social cognitive theory (SCT) [90]. The UTAUT consists of four predictors of intention and usage: performance expectancy, effort expectancy, social influence, and facilitating conditions as well as considering four moderators of important relationships: gender, age, voluntariness, and experience [90]. These four main constructs of the UTAUT are defined, with regards to ePHR, as the following: Performance expectancy is defined as the degree to which an individual believes that using the ePHR will help him or her to attain gains in their overall health performance, Effort expectancy is defined as the degree of ease associated with the use of the ePHR, Social influence is defined as the degree to which an individual perceives that important others believe he or she should use the ePHR, and facilitating conditions are defined as the degree to which an individual believes that resources and technical infrastructure exists to support use of the ePHR. These four constructs are the predictors of the user's behavioral intention to accept and use a certain technology. The behavioral intention, in consequence, predicts the actual behavior. In 2012, Venkatesh et al. introduced an extended UTAUT2 model by adding three new constructs namely: hedonic motivation, price value, and habit to study the technology acceptance and use in a consumer context [151]. The UTAUT2 model provides a significant improvement in the variance explained in behavioral intention and technology use compared to UTAUT [151]. The UTAUT has been used and utilized in many areas including health information technology area. The UTAUT utilization include studying the user's adoption of mobile banking in combination with TTF [152], examining the adoption of E-Government Services [153], studying student's perceptions toward using course management system in the education [154], and investigating the mobile commerce user acceptance in China [155]. Many researchers examined the health information technology applied the UTAUT to understand the individual's acceptance and usage of a certain technology. A study conducted in Thailand aimed at identifying the factors influencing the HIT adoption and use using a modified UTAUT model [156]. The study found out that the factors influencing IT acceptance are performance expectancy, effort expectancy, social influence, and voluntariness as well as previous IT experiences, intention to use the system, and facilitating conditions predicting the health IT use. Tavares and Oliveira studied the patient's adoption and use of the patient portal using modified UTAUT by adding new constructs related to health-care area [157]. The findings suggest that performance expectancy, effort expectancy, habit, and self-perception are the drivers of the user's intention to adopt the patient portal. The predictors of the actual behavior include behavioral intention and habit [157]. Venkatesh et al. applied a modified UTAUT, to fit with health area context, to examine the doctor's intention to adopt and use EMR [158]. The model performed well in terms of predicting the behavioral intention and the actual use [158]. The UTAUT and UTAUT2 have proven their capability to predict the intention and behavior toward technology acceptance and use in various areas including health information technology.

The following Fig. 4.5 shows the depiction of the UTAUT [90]:

The following Fig. 4.6 shows the depiction of the UTAUT2 [151]:

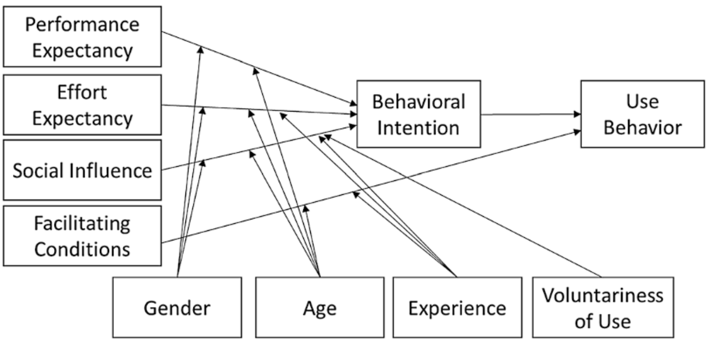

Fig. 4.5 Unified theory of acceptance and use of technology [90]

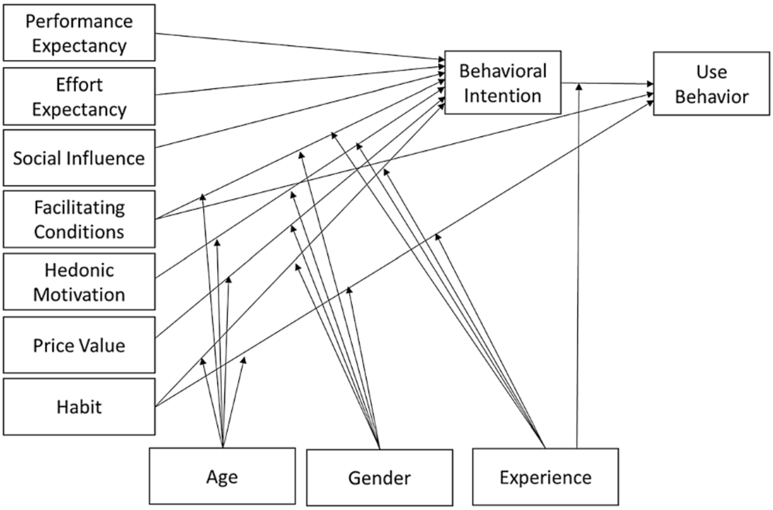

Fig. 4.6 Unified theory of acceptance and use of technology "2" [151]

4.14.6 Diffusion of Innovation Theory (DOT)

The introduction of new innovative technology in the area of health IT is very important as its diffusion and widespread adoption of it. Rogers [159] proposed definitions for innovation and diffusion. The innovation itself is "an idea, practice, or object that is perceived as new by an individual or other unit of adoption." And the diffusion of innovation is "the process by which an innovation is communicated through certain channels over time among the members of a social system." This definition emphasizes four elements of the diffusion of innovation which are: innovation, communication channels, time, and social system. The characteristics or attributes of innovations are relative advantage, compatibility, complexity, trialability, and observability. It is important to understand the innovations characteristics as they help in explaining and determining their adoption rate and they influence the diffusion of innovation. Thus, it is essential to understand the different type of innovation adopter categories as they classify the members of a social system in terms of innovativeness: innovators, early adopters, early majority, late majority, and laggards. Innovativeness is defined as "the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than the other members of a system" [159]. Rate of adoption as well explain the speed in which an innovation adopted by individuals. Many research studies have been conducted to study the diffusion of innovation and its application in various areas such as health technology. Tornatzky and Klein researched the innovation attributes and came up with most ten attributes that influence technology adoption: compatibility, relative advantage, complexity, cost, communicability, divisibility, profitability, social approval, trialability, and observability [160]. The study suggests that compatibility, relative advantage, and complexity attributes have the most significant impact on the innovation adoption. Agarwal and Prasad studied the personal innovativeness in the information technology area as a new predictor of technology acceptance [161]. They suggest that relative advantage, ease of use, compatibility, and personal innovativeness in the IT area are factors influencing the intention to use a new IT. Another study conducted by Agarwal and Prasad examined the two outcomes, the initial use of an innovation and individual's intentions to continue using the technology in the future, to represent user acceptance behavior [162]. They proposed a research model that considered seven constructs: relative advantage, ease of use, compatibility, trialability, visibility, result demonstrability, and image. Thus, these constructs influence current use and in return predict future use intention. The innovation diffusion theory has been examined in the health IT. A study utilized the diffusion of innovation model to study how patients perceive the PHR [163]. The findings showed that the factors ease of use and relative advantage are greatly perceived by the PHR users than nonadopters. These two factors predict the PHR value as well. Another study used the diffusion of innovation theory to understand the factors influencing patient acceptance and use of consumer e-health [164]. The e-health innovation examined is the e-appointment scheduling service in a primary care clinic setting. The findings showed that only "innovators" adopted the new service as the adoption rate is increasing very slowly. The study revealed the factors influencing the low adoption rate as: inadequate communication about the new service, lack of demonstrating the value of the new service, patient prefer to orally communicate with receptionists, and some patient's characteristics such as low computer and e-health literacy, and lack of Internet access [164].

4.15 Conclusion

Electronic Personal Health Record (ePHR) helps support patient-centered health care by allowing patients to access their health information from their provider's EHR. This literature review is intended to provide an overview of the adoption and use of the tethered electronic personal health records (ePHR). It examined the ePHR definition, types, importance, impact on health outcomes, capabilities and features, and adoption barriers. The literature presents the health-care providers, nurses, and physicians perspectives toward the ePHR. It investigates the factors influencing the adoption and use of the ePHR by patients. This literature review goes over the national and global initiatives toward the adoption of health IT solutions. The major adoption and acceptance models that have touched upon the ePHR adoption have been investigated to understand the adoption factors influencing the intention to adopt a certain technology.

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Chapter 5
A Practical Strategic Planning Approach for R&D Organisations

Husam Arman

5.1 Introduction

Although the objectives of the strategy can differ based on the situation as explained by the strategy guru [1] who put together five formal definitions of strategy, the essence of the strategy is still based on two fundamental questions: where to go and how to get there. Therefore, the strategic planning approach should attempt to answer these two questions.

The content of strategy and the process of strategy are different and the relationship between the two has crucial implications, the content of strategy including the different levels of strategy: corporate, business, and operational units, while the process of strategy is about process issues related to the quality of the strategy that emerges from the process and its appropriateness for the organisation, and the commitment to implement the strategy [2]. We found in our study that the process of the strategy is critical and can determine in advance the gap between the plan on paper and the implementation extent. As long as the main objective of the strategic planning is understood as changing the business in order to achieve mission and goals [3], the strategic planning process itself needs to be dynamic and responsive based on the requirements. A pragmatic and simple approach to strategic planning is needed to attract the attention of decision-makers in organisations [4]. Moreover, the planning methods that are agile, able to sustain a long-term focus while also allowing for adjustments to meet the rapid pace of change in technology and innovation [5] are ideal in such dynamic situations. For instance, Hoshin Kanri method meets the agility requirements since its basis comes from the quality

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concept of the Plan-Do-Check-Act (PDCA) cycle where the planning and the review are integrated [6].

However, the selection of strategic planning methods depends on several factors including the technical-organisational conditions, the organisation's readiness for problems, the subject using the method, methodical preparation of the persons applying the method and their level of qualifications, and the CEO's influence [7].

In any strategy development process, a vital component is the planning for technology development to formulate technology strategies aligned with the corporate strategy [8]. For R&D organisations, the strategic objectives are developed to address strategic technological issues and provide technological solutions which is the core business of the R&D activities. Therefore, strategic planning in R&D organisations needs different approach to be able to deal with uncertainty associated with the speed of technological developments and changing demands.

In such environment, the technology strategy would be the driver of the organisation and not the enabler. It orchestrates the development and the use of technology solutions to serve the clients seeking scientific-based solution from R&D organisations. The technology strategy in business is responsible in meeting the type of competitive advantage a firm is trying to achieve in the firm's generic strategy [9], but in R&D organisation it is the central concept of strategy.

Striking a balance between the two distinct traditional approaches to strategy development regarding the emphasis on core competences as a resource-based approach [10] and the positioning approach pioneered by Porter [11] is very essential to any R&D context. Regardless of the internal or external driver of crafting strategies, the strategic planning process varies between systematic and "rational" steps as per theory [12] and the dynamic and flexible approach advocated initially [13]. The latter approach has gained the interest of small firms and start-ups due to the inherit market niche strategies and the agility of start-ups culture that follow the lean and experimental approach instead of a sequential lengthy process [14].

This paper is a practice-oriented document, and the researchers were involved in every step of the implementation of the theoretical framework, and therefore it should be easy to read and of interest to the practitioner as well. The objective of this paper is to demonstrate the importance of the strategic planning approach to prioritise and influence the research agenda of an R&D organisation using practical and simple management tools. After the background section, the methodology is briefly explained, and then three sections are dedicated to show the role of strategic planning an R&D setting, and highlight the key tool and its contribution before the conclusion.

5.2 Background

5.2.1 Strategies in Research and Development

Innovation has been an important driver for competitive success in many industries, and it has shown a high impact on society if managed strategically [15]. The rapid technological change and the resulting new innovations force organisations to improve their agility to be able to adapt to and take advantage of the new opportunities and minimise any threat. Therefore, success belongs to those organisations that have the capacity not only to adapt to change, but also to thrive on it [16].

For R&D organisations, it is important to rethink the way they plan and manage their research activities considering the speed of technological and social changes. Therefore, improving the productivity of R&D organisations is becoming a challenge. This stems from two basic reasons: (1) the character of the organisation, and (2) the type of people involved in R&D [17]. Aligning R&D activities with corporate strategy where technology managers and top management work together, the concept of portfolio can be utilised effectively in order to manage risk and maximise profits, which could guide a good strategic plan [18]. Although this might not be enough unless a seamless synergy is achieved between strategy and innovation, and both complement each other where innovation supports strategy, and strategy supports innovation [19].

In the current knowledge and creative economy, effective management of R&D is crucial, since it is not just about the size of R&D budget and the percentage of R&D expenditure rather managing the innovation activities in general. This was the philosophy of Steve Jobs when he compared Apple to other technology firms in terms of R&D expenditures. He said in 1998 that "innovation has nothing to do with how many R&D dollars you have" [20]. Moreover, the rapid pace of technology is forcing organisations to develop a different set of management tools that can deal with such challenges. The cases documented [21] in the ICT sectors demonstrated how corporate strategies are struggling to deal with uncertainty using the traditional strategic planning approaches. As a result, disruptive innovation has become a concern not just to large firms, but even small and medium-sized enterprises. If, disruptive innovations are misunderstood, managers may end up using the wrong management tools for their context and their business environment, which can affect their chances to succeed in such turbulent situation [22].

Utilising R&D outputs require appropriate management toolkit and working knowledge in order to direct these efforts towards making an impact on the performance of the organisation. This includes financial and innovation performance. This require investing in activities related to accelerating technology exploitation and commercialisation, building extensive internal and external linkages, and pursuing business-driven R&D while encouraging experimentation and risk-taking [23]. These are fundamental strategic thrusts for an R&D organisation to prosper whether it is an independent public R&D organisation or a centre of excellence within universities.

The strategic planning specialists and management consultants are under further pressure while trying to help R&D organisations to focus their efforts towards meeting strategic objectives of current and future stakeholders [24]. Therefore, corporations that rely heavily on R&D need innovation strategies that favour an 'incremental' approach (Ansoff's school of thought) as opposed to the common practice of 'rational' approach [13, 25]. The former approach can be more effective and consistent for an R&D organisation which comfortably assumes imperfect knowledge of the environment and the future development. Hence, it should be willing to change its strategy and even its approach to strategic planning in the light of the development and changes that are frequently received and analysed. Moreover, R&D organisations is biased towards allocation of resources to innovation activities, unlike the business objectives of CEOs of corporates who want to acquire immediate profits.

Therefore, there is a need to balance and manage innovation portfolios. According to Nagji and Tuff [26], companies can outperform their peers if they optimise their innovation portfolio by allocating resources of about 70% to core initiatives (incremental changes to existing products and services), 20% to adjacent ones (complementary initiatives to leverage current products in a different market), and 10% to transformational ones (efforts designed to create new offers or a totally new business). This concept is very significant for independent R&D organisations and R&D functions within corporation to keep up with the rapid pace of technological changes and meeting urgent client needs. Therefore, they need to build their own dynamic capability that can accommodate the paradigm shifts in R&D strategies. Although it is difficult to make continuous changes to the management processes in any organisation, it has been proven necessary for the long-term success.

5.2.2 Strategic Planning at KISR

Research institutions continue to be one of the main sources of innovations, especially in developing countries, due to the lack of national corporations with extensive R&D capabilities. The strategic orientation of a research institution should be based upon a framework for understanding important global trends, future prospects, regional perspectives, as well as the corresponding country and community aspirations. This understanding should be reflected in the long-term vision and the research agenda of such institutions. It is essential that the institutions have a progressive system of management that allows them to maintain a futuristic vision that serves the scientific needs of their region and incorporates global scientific advancement.

Kuwait started an early regional leadership position in scientific research when it established KISR as an independent national scientific research institute. KISR's initial role was dedicated to developing three fields of national importance, namely, petroleum, desert agriculture, and marine biology. Since then, KISR's role and responsibilities have expanded greatly to include the advancement of national industry and the undertaking of studies to address key challenges, such as the preservation of the environment, sustainable management of Kuwait's natural resources, responsible management of water and energy, and development of innovative methods of agriculture. Today, KISR consists of four research centres with about 580 researchers and engineers, over 100 laboratories, and three support sectors housed at nine locations. KISR conducts scientific research and performs technological consultations for governmental and industrial clients in Kuwait.

At KISR, strategic planning has been one of the key functions that has been practised since 1978 in a form of series of five-year strategic plans. Each of these five-year plans included a diversified set of goals that were oriented towards achieving KISR's goals in solving Kuwait's current and anticipated challenges. KISR completed a strategic transformation project in 2010 with the help of Arthur D. Little. The aim of this project was to transform KISR into R&D Center of Excellence focusing on innovation in support of the State of Kuwait. The project resulted in a new vision, mission and a long-term strategy with a 2030 roadmap. The project also resulted in a new organisational structure and improved internal processes. Therefore, the first five-year strategy of KISR's 2030 vision was the 7th Strategic Plan. In this strategic plan, the research agenda included a large number of proposed research activities due to the highly positive atmosphere after the transformation project; the high expectation of hiring new researchers; and the anticipated improved efficiency of optimised support processes.

KISR's long-term strategy consisted of five strategic thrusts as shown in Fig. 5.1. These thrusts were designed to fulfil the new vision by focusing on client's needs, collaborating with leading research institutions, building research centres in application-oriented areas, commercialising technologies and building a culture of achievement and excellence.

The 7th Strategic Plan made reasonable progress along the five strategic thrusts, by improving stakeholder engagement, creating key account management process, signing various MoUs with international research institutes, investing in new research facilities, establishing a division for commercialisation and revising several high impact management processes such as publication and promotion policies. However, the general quantified achievement of the 7th Strategic Plan was not as expected based on the self-assessment and the strategy evaluation conducted by the strategic planning team at KISR utilising stakeholder feedback. The justification of the aforementioned was rationally necessary and can easily be documented with direct corrective actions such as the lack of manpower (mainly researchers),

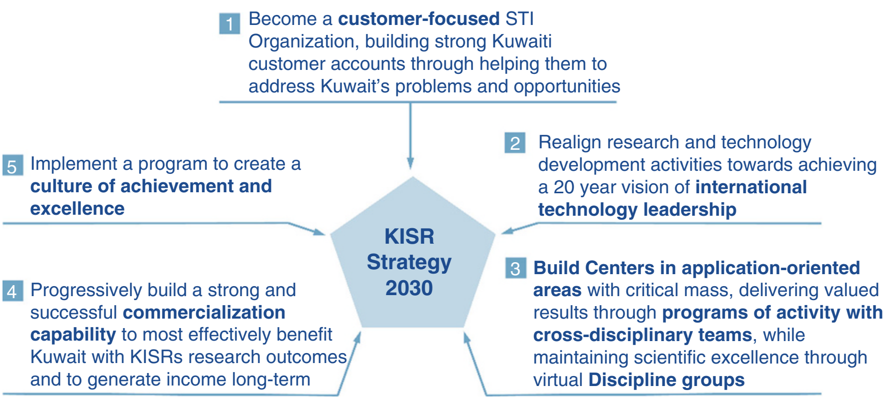

Fig. 5.1 KISR's five strategic thrusts for 2030

inefficient support services, and bureaucratic management processes. Nevertheless, the top management and the strategic planning team reacted by questioning the strategic planning approach and decided to amend it to overcome some of the aforementioned challenges and ensure that an effective process is in place shown in the following sections.

5.3 Methodology

Since the significance of this work was to highlight the challenge that strategic planning faces in a R&D organisation, and how if managed with flexibility can be useful, this chapter proposes practical solutions that can be helpful to practitioners in the field of strategic planning for research institution in similar organisation. The methodology used in this research was empirical and explorative, since there is a need to describe and document the current situation and explain factors which together cause a certain phenomenon [27, 28].

The case study approach is generally superior when answering "how" questions about a specific topic that deals with the "real world" [28]. However, this study was not traditional case study research where the researcher is a distant observer, rather the researcher and the stakeholder (i.e., the research object) work collaboratively together on the problem and learn jointly. Therefore, the researcher work "with" rather than working "for" stakeholders, and reflect on the experience from living in complex situations together [29]. This was possible since the author was working full time in the case study enterprise.

This study aims to answer the research question "How the strategic planning approach can influence the research agenda of public research institute?" In this study, qualitative data were mainly used through observation, interviews, group discussions and workshops organised by the researchers to carry out the case study at the Institute in addition to the feedback workshops after the strategic planning activity. The empirical nature of this study made it easy to continuous learn, iterate, collect feedback and make changes accordingly.

5.4 The Need for a New Strategic Planning Approach

In the 7th Strategic Plan, KISR followed fairly standard strategic planning approach which included revisiting the vision and mission, conducting internal and external assessment, deriving strategic objectives cascaded at various levels (Research Centres/Support sectors, divisions, and programs/departments) and projects related to these objectives.

As to KISR 8th Strategic Plan (2016–2020), the approach was similar but important amendments and new tools were utilised to address various challenges. These included the gap between the plan and the implementation which was due to lack of resources such as manpower, and in particular experienced researchers, the diversion from addressing client specific needs, spreading too thin with long list of planned research activities and the slow internal processes such as procurement and recruitment.

Considering the aforementioned challenges, several corrective actions and strategic initiatives targeting mainly the support sector processes to optimise the key internal processes were identified in the internal assessment exercise as part of the strategic planning activity. However, the strategic planning team challenged the strategic planning approach itself and decided to revisit it with the objective of addressing proactively the identified issues.

It was agreed with the top management that the main focus of the 8th Strategic Plan is to ensure that KISR is consistently providing the highest quality research and technical services to its key stakeholders in Kuwait. It should include an honest and complete assessment of how we are doing and accordingly lay out a strategy for closing any gaps, including any modifications to KISR's portfolio of research programs. One important aspect was revamping planning to become an integrated approach at KISR where the strategic planning process is closely linked to other key planning and evaluation activities such an annual planning, key account management, science and technology (S&T) planning and performance management.

5.5 The Influence of the Strategic Planning Approach

The modified strategic planning approach at KISR was designed to steer the research centres to focus their resources so that they could commit with a high level of confidence to meeting the priority elements of their strategies, which meant making conscious decisions to stop supporting less important activities, while selecting a portfolio of activities across their research programs to secure truly innovative solutions to key clients in addition to considering the development of innovations that would have positive impact and position KISR for long-term success.

Moreover, specific steps for executing the proposed strategy were required to ensure more attention paid to the factors that may enable the strategy particularly with respect to process improvement within the sectors and capability development in every organisational unit. Table 5.1 shows the main challenges and the resolutions that were introduced in the 8th Strategic Plan approach.

This perspective of considering the strategic planning process as a problem-solving strategy was adopted as a philosophy to resolve the current issues/challenges since good strategy results from investing the time to make the hard choices to gain focus and identifying obstacles and working out how to deal with them [30].

The terminology that was introduced during the strategic planning process was important in addressing the challenges faced, such as using the term "solution areas" that each program is required to deliver. The "solution" gave the message that the research should result in a tangible output and application to the client, although

Table 5.1 Key challenges and resolutions through the strategic plan approach

Issue/challenge	Resolution
Lack of human resources	Focus on the critical few
Too many priorities	Focus on the critical few
Diversion from addressing client specific needs	Key account management
Spray-gun approach	Portfolio evaluation
Lack of active review	Integrated performance management system

it could be addressed by more than one research project or technical service (‘area’). This was a deliberate approach for this specific stage for KISR to focus on meeting key client needs. However, the key function within the strategic planning model is the portfolio evaluation matrix (PEM). PEM was introduced to influence the research agenda to become more client focused, address the critical few and most importantly produce a balanced portfolio of research activities. This was accomplished using a tool that can communicate visually the impact of the various solutions areas within each program and at the centre level. As a result, the strategic areas at the centre level can be identified, and hence, the contribution of each research program.

5.6 Deriving the Strategy Through the R&D Portfolio

Aligning resources spent on R&D activities with the strategic objectives of any organisation has been one of the most challenging issues, in particular, to technology-based firms. The strategic planning process ideally ensures that the list of R&D projects is proposed to serve the market and product strategies. The alignment, if it happens, is usually enforced by embedding it in the evaluation criteria. This alignment criterion is useful in the evaluation process, but will not necessarily result in a balanced portfolio that meets the strategic objectives which could lead to different directions. For instance, there are objectives regarding growth in market share and profits, focusing on the cash cows projects, and others, looking at blue sky areas.

Decision-making tools and, in particular, R&D portfolio analysis available in the literature are not used widely due to the perceptions held by the R&D managers that the models are unnecessarily difficult to understand and use and do not engage practitioners in collective creative manner. Cooper and his colleagues provided in several publications (such as [31, 32]) various practical and simple to use bubble chart tools including risk-reward matrix which proved to be useful and practical. Part of these sets is the impact-effort matrix that has been used in many contexts including Lean and Six Sigma [33].

The concept of this tool has been used as part of the strategic planning process in order to make sure that the R&D strategy is aligned with corporate strategy in the business context. For R&D organisations, we found it useful not to serve the alignment purpose, rather to be the core of the strategy development, since it can be utilised to reflect the conceptual meaning of a strategy that address the two key questions; “Where do you want to go” (i.e., the ‘Impact’ you want to achieve) and “How to get there” (i.e., the ‘Effort’ needed to execute the strategy and deliver the required results, which was the main challenge at KISR). This concept can be utilised in similar organisations as long as the criteria are translated as per their context, mission, and their strategic objectives. This tool as with other similar tools requires an average level of organisational preparation, highly qualified facilitator where an external and internal consultant is needed [7], and this was the case when we applied it at KISR.

The generic matrix that we developed is based on the aforementioned concept, but we used the terms impact and ability. This generic framework can be used to translate any strategy to a visual and practical decision-aiding tool. The impact would reflect the expected contribution of the R&D programs and projects on the predefined strategic objectives of the organisation, and these can be grouped based on the desirable portfolio shape of the organisation to produce a balanced portfolio of activities.

5.7 The Portfolio Evaluation Matrix

One of the important lessons learned from the execution of the 7th Strategic Plan was that the number and magnitude of the projects proposed by the programs which far exceeded the organisation’s ability to support in terms of manpower, facilities, equipment and administration. To correct this problem, the 8th Strategic Plan needed to focus KISR’s limited resources on those initiatives that will have the largest impact on meeting national challenges, client’s mission critical problems, and KISR’s reputation and financial commitments. Each centre followed a sequential process to evaluate its existing research programs, determine which programs would be continued, added or modified within the 8th Strategic Plan and to identify the specific solution areas that would form the heart of the research centre’s activities over the next five years.

This process is briefly described in Fig. 5.2 which shows the main features of the process. The PEM is a critical function in the process which serves three important objectives as follows:

– To critically evaluate each of the programs and solution areas
– To help in making decisions with regard to aligning and directing programs towards the overall centre strategy
– Select those program solution areas that the centre will emphasise and give the highest priority.

PEM was designed to help the centre management in evaluating the solution areas that were proposed in the program strategies. The two-dimensional matrix as shown in Fig. 5.3 consists of two major criteria; the potential impact that the solution area may have in the next five years and the ability of the current program team to

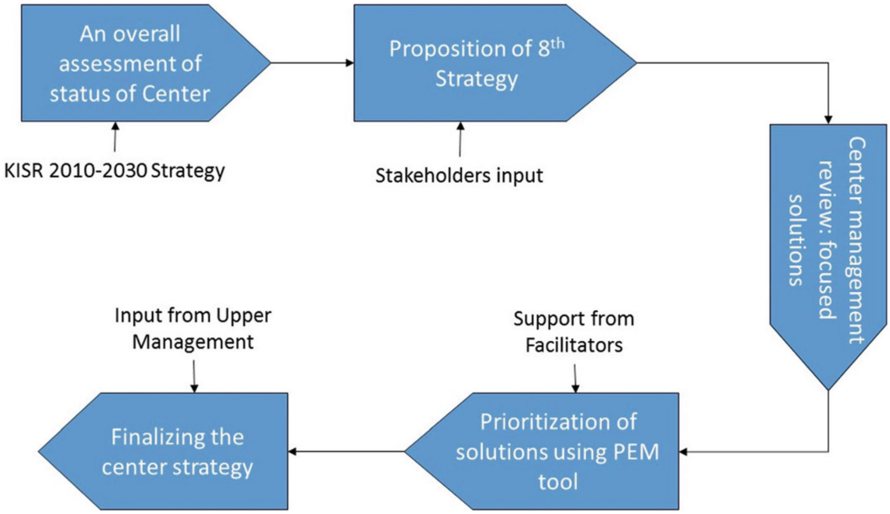

Fig. 5.2 Process overview for the development the research centre agenda

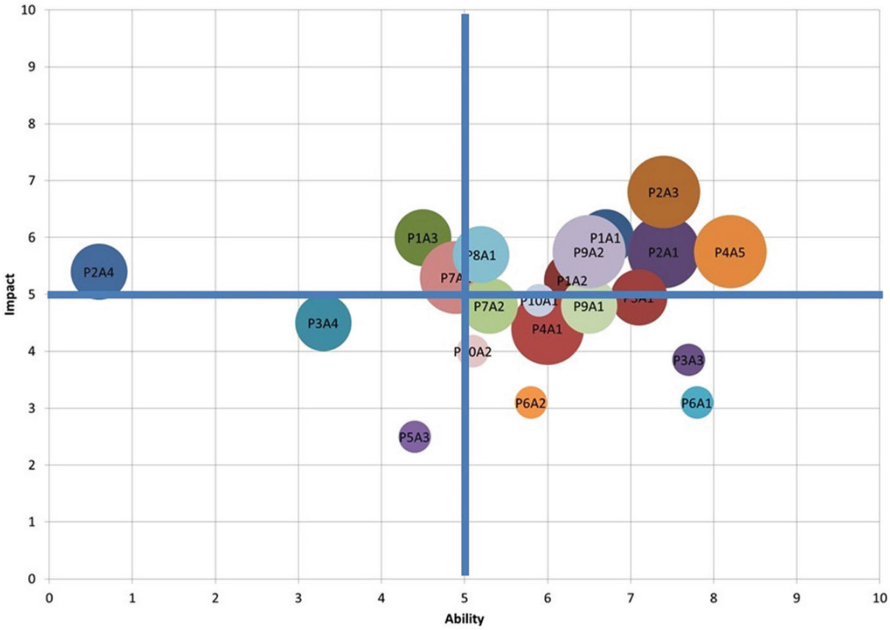

Fig. 5.3 Portfolio Evaluation Matrix (real example from a research centre)

deliver what is being promised. Using this preliminary ranking as a guide, the centre management can then make judgment decisions on program/solution area priorities within the centre. The codes used in the chart denote to the program and solution area (e.g., P2A1 is the first solution area in research program 2), and the size of the bubble is the anticipated revenue stream from technical services/projects. The specific data about the solution areas within each program are not shown to maintain confidentiality.

To calculate the potential impact of each solution area, three criteria with specific weight for each were used to evaluate each solution area. These criteria were derived from KISR's five strategic thrusts of the 2030 strategy (see Fig. 5.1). Each solution area is scored on 1–10 scale points as per the detailed definition of each criteria where 10 is the highest value.

- *The anticipated impact in meeting a national challenge*—Solution areas directly related to finding solutions for national challenges and expected to make high impact.
- *The anticipated revenue stream from technical services/projects and commercialisation of IP*—Commercialisation is broadly interpreted to include spinouts, IP income (patents, copyrights, license) and technology transfers.
- *Enhancement of KISR's regional/International reputation*—Outputs to be considered for evaluation include high impact publications, joint publications/ activities with international partners and regional STI leadership initiatives such as the Regional Persistent Organic Pollutants laboratory, patents and attracting senior hires with an international reputation.

To calculate the ability to deliver results, three criteria were used to evaluate each solution area using 1–10 scale point as per the detailed definition of each criteria where 10 is the highest value.

- *Strength of the program leadership*—The talent, experience, motivation and track record of the program manager and the identification of an adequate backup.
- *Quality and depth of the program staff*—The availability of adequate professional and technician support for program execution.
- *Adequate facilities*—The appropriateness of the current facilities and facilities approved and currently under construction.

The output of this process is not an overall score, that is, a weighted average of the scores for impact and ability to implement, rather a matrix using bubble diagram function that was customised in an Excel-based program using VBA tool which shows four quadrants that can be addressed using different strategies;

- *High impact-High ability:* These are the expected winners where the anticipated impact is almost certain, hence, the centre's image will rely on them and it will be a star, if expected revenues are high (e.g., P2A3, P2A1, P4A5 in Fig. 5.3)
- *High impact-Low ability:*The solution areas here need special attention by the management and rigorous assessment to all the factors need to be addressed with urgency. These include recruitment, procurement, partnerships, consultants, etc. (e.g., P2A4 in Fig. 5.3).

- *Low impact-High ability:* The solution areas that fall here should be the ones that the centre depends on in generating revenues, expanding its market, unless the expected revenues are not high (i.e., the size of the bubble), then, a possible strategy is to divert resources to other solution areas where applicable or even use retraining strategies to enter new research area (e.g., P6A2, P6A1 in Fig. 5.3).
- *Low impact-Low ability:* The solution areas are not desirable here, and they should not be pursued. Therefore, it is important to revisit and reassess these solution areas and possibly abandon them at the planning stage and reallocate planned resources (e.g., P5A3 in Fig. 5.3).

The results of the overall ranking of the research centre's solution areas are not the end of the process. Further review and analysis and iterations to ensure that a balanced portfolio of research activities is maintained. To do this, the impact criteria are also plotted using the bubble chart function (see Fig. 5.4). For instance, the research centre was able using this tool to balance at the planning stage, the various activities that can make high impact on meeting clients' needs and address national challenges (e.g., P1A1, P2A3 and P8A1), activities that will generate high-quality publications and STI leadership initiatives (P3A3, P2A1, P2A4,P8A1, P2A3, P1A1 and P10A1), activities that can result in direct revenues or potential patenting and future commercialisation (e.g., P4A1, P7A1, P2A1, P3A1 and P2A3) or combination of more than one of the aforementioned (e.g., P2A3, P1A1 and P10A1).

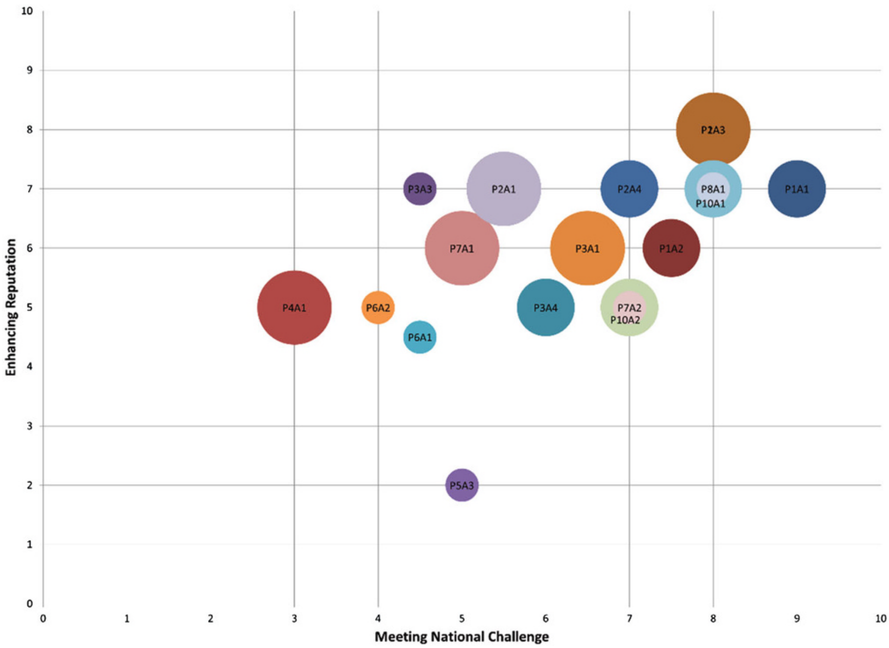

Fig. 5.4 Impact assessment to help in balancing the portfolio of research activities

The aforementioned process has eventually helped the institute to focus on the critical few areas; and therefore, it has developed a much shorter list of key projects within each research program structure that meets the multiple goals of the institute. This has been a very useful approach from a management perspective.

However, the feedback was not received with the same motivation from the staff and research program managers, since they are usually excited and motivated to conduct a large number of research ideas based primarily on their interest rather than their alignment to the organisation's strategy. Therefore, they found it difficult sometimes to accept the resulted portfolio and especially if it redirected or undervalued their perspective on the program contribution when compared with other research activities. This challenge was overcome in the limited cases where the management of the research centres involved, at early stages, the research program managers, and in some occasions senior staff. Moreover, it is designed to make the process as transparent as possible, in addition to providing enough window for feedback and discussion.

5.8 Discussion and Conclusions

Managing R&D organisations is becoming more complex with the pressure to become lean and yet deliver tangible outputs and innovations that justify the investment of the resources in the form of R&D activities. The response to such a challenge is usually by adding further complexity to the strategic planning and evaluation processes. Although this can work, communicating it to the mass of middle management and researchers can be challenging.

The simple participatory process that we have used proved to be more effective in addressing the need for a balanced portfolio of activities that serve the multiple organisation's objectives.

This chapter has demonstrated how the strategic planning approach and the new toolkit that was introduced have helped in influencing the research agenda of the organisation by analysing the strategy communicating it visually utilising structured steps. Introducing new tools such as the portfolio evaluation matrix has helped the research centres at KISR to focus their effort and energy on a manageable and balanced portfolio of research activities that meet the strategic objectives of the organisation according to its long-term roadmap. For instance, the resulted research strategy addressed the issues regarding the lack of resources and scattered effort. Moreover, the practical visual approach helped design a research agenda that includes a mix of research activities that are also capable of meeting the key performance indicators associated with the five strategic thrusts of KISR's 2030 strategy effectively, since these were addressed in the planning stage while prioritising the research solution areas in totality. Hence, the planned research activities are spread in an optimised manner in front of the middle management who are going to lead the strategy execution.

These conclusions were documented based on the feedback that was captured from various interactive workshops with all the management of the research centres. The main lesson learned from this exercise showed that a standard and a rigid strategic planning process will not serve a research organisation which evolves naturally and continuously due to the dynamic external conditions. Therefore, adopting an agile approach and introducing innovative management tools within the strategic planning approach are important to enhance the performance of the strategic planning of any research organisation. Moreover, considering the workshop feedback on the 8th Strategic Plan approach, a further modified approach will be considered with the aim to address the important issue of producing a truly integrated institute strategy and reflecting an optimised research portfolio at the institute's level.

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Part II
Technology and Engineering Management Tools

Introduction

This part focuses on technology and engineering management tools. The topics include product concept development, design process of product, technology selection and adoption.

Elicitation and formalization of user desire and potential experience are the biggest challenges of the design. Understanding an in-depth expression of desires for today and tomorrow and its impact on user behaviour is a key to a successful concept design. Through this process latent factors are sought and discovered by a systematic investigation. Once the candidates' lists of features are obtained, their influence on new product desirability is ranked, so the proper design parameters are prioritized. Kumar has studied automotive infotainment systems and tried to highlight the consumer expectations.

Designing includes a bunch of small problems to be resolved where creativity matters. In many situations creativity may not be exposed easily, either a stimulus or a systematic enumeration of possible alternatives might be. Experience of the designers is critical when they aim to end up with a good design. Experience and know how pool of a community might be reused as a knowledge transfer from past stories. Instead a more systematic way to vitalize this approach is offered by a well-known method called TRIZ. The TRIZ method had been mature in many decades and received a wide acceptance from design community. The approach has produced a long list of problem-solution library as design patterns, which are attempted to be utilized in case library solution match with the focused problems. Taşkın et al. apply TRIZ method on household appliances and compare with another approach.

Many new products are created by the support of innovative technologies. So searching and focusing on effective technologies in the value chain become critical while managing the innovation process. Still there might be more than one technology where each has different level of contribution to the innovativeness of the product. Designing a product sometimes is selection and acquisition of appropriate composition of technologies. Ureten has studied different additive manufacturing

(AM) technologies in health care industry. A hierarchical decision modelling (HDM) had been utilized to evaluate AM technologies for the production of metallic hip implants.

Products built even perfectly have to prove that they fulfil the requirements of the users. The task and design fit is sought before the product design starts as well this is checked after the product is launched. Information systems capability and underlying technology are improving day by day which becomes more competent. On the one hand, the developers are so ambitious to advance the existing product, and on the other hand, potential users have to make a smart decision to select most appropriate technology that will support their business operations. Dahooie et al. apply a systematic method to examine and evaluate selected set of business intelligence (BI) software. The authors have employed a fuzzy multi-criteria method after identifying more than 30 criteria which are basic features of the software.

Energy is the heart of all the industries. Not only the economic but also technological, environmental and social aspects of the energy production are worth to consider while making strategic investment decisions. Different alternative energy forms for electricity production are available and each has varying effect on all aspects. Dahooie et al. have studied four different renewable energy alternatives such as wind power, solar energy, biomass and hydroelectricity to make a good selection. Multi-criteria decision models, CCSD and COPRAS, have been deployed considering 20 different criteria under four main aspects while the alternative-criterion assessment had been realized by field experts.

User's involvement and interaction style may be very important in efficient use of energy. Shaping the load by managing the demand of user may employ different techniques including gamification. These are sophisticated systems which help users develop in-depth understanding of the energy issues. Oztaysi et al. examine gamification and its implementation in the field of energy demand management. Four alternatives consisting different gamification approaches composed of different gamification elements are evaluated considering four criteria using a multi-criteria decision model called Hesitant Fuzzy AHP.

Chapter 6
Study on Consumer Requirements for Automotive Infotainment Systems

Aswin Sampath Kumar and Tuğrul Daim

6.1 Introduction

The core function of marketing is to discover and stimulate opportunities for firm's output ([1], p. 10). In doing so, market research plays an important role in gathering information that is crucial for making business decisions ([2], p. 36). Market research is extremely important, especially for technology-based companies to understand customer direct and latent needs ([3], p. 1003).

6.1.1 *About the Automotive Infotainment Systems Market*

Infotainment includes features like radio reception, audio, video, navigation, telematics and a user interface to the infotainment system [4]. Rapid growth in mobile phone adoption and consumer electronics makes the end consumer expect the same features from car infotainment systems. The audio and video content that is being played on the infotainment system is increasing continuously [5]. Due to all these strong requirements, the infotainment market is a very attractive business. In fact, the automotive semiconductors or value in the car is expected to be 40% of the

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car value itself ([6], p. 11). However, the automotive infotainment market has been slow in adopting digital technologies compared to the consumer electronics market. This is attributed to the complicated task of running the personalized settings in a separate environment without affecting the core functionality of the car safety features.

6.1.1.1 Challenges in the Infotainment Value Chain

The Original Equipment Manufacturer (OEM) produces and sells cars to the end consumer. The OEMs face a challenge of rapidly changing demand and expectations from customers [7, 8]. These challenges force OEMs to design cars that are attractive in their market segment with minimum time to market [9, 10]. Since it is difficult to accomplish all this goal in-house, they outsource the certain tasks to Tier-1 suppliers and later integrate this into the production line. This gives them the advantage of low cost, increased efficiency and low labor cost ([11], p. 131). This OEM-supplier relationship helps them to focus on their competency and at the same time promote innovation in product development [12].

Due to rapidly changing requirements and reduced time to market for car manufacturers, Tier-1 AIS suppliers are faced with enormous time pressure. Schneiderman [6] claims that technological advancements have helped in reducing the design cycle time from 60 months to about 24–36 months much faster than 5 years ago. He also mentions about this reduced design cycle as, “placing pressure on system designers to more quickly prototype and demonstrate their designs to original equipment manufacturers (OEMs). The turnaround time for design and development into production for infotainment and driver information systems keeps getting shorter” ([6], p. 12). Additionally, these Tier-1 firms supply for multiple car makers and in multiple platforms. All these factors foster Tier-1 Automotive Infotainment Systems (AIS) companies to maintain a strong relationship with its semiconductor suppliers.

The Tier-2 AIS semiconductor industries are faced with the challenge of knowing in advance the future market requirements, much ahead of the OEMs and Tier-1 companies. Because AIS semiconductor companies face derived demand for their products based on the Tier-1 products demand, they should be able to respond quickly to market changes and have products developed even before the Tier-1 customers face the requirement. Therefore, it becomes important for the Tier-2 AIS semiconductor companies to forecast the market trends in advance to facilitate product development at their level. This also helps them to gain a competitive advantage by differentiating their products and help Tier-1 companies and OEMs to be quick to market.

6.1.2 Background of the Project

According to Porter [13], firms innovate in order to stay ahead of its competitors by differentiating their products and services. This fosters growth in their sales and creates a global competitive advantage. Furthermore, due to the emerging trend of product commoditization [14] in markets, it is important that firms find means to differentiate their service and products to be the successful market leader ([15], p. 312).

As a first step towards product differentiation, it is important that firms have a good understanding of their customer needs ([16], p. 25). This helps them to promote innovation and create value in their products and services offerings [17]. Surprisingly, market research in Business to Business (B2B) is not done quite extensively as done for Business to Consumer marketing (B2C) context ([16], pp. 25–26).

In the B2B market, where firms supplying products to other firms, the demand for the supplying firm products are derived from the immediate customer's product demand ([18], p. 72). The derived demand is stronger for companies which are located at the beginning of the supply chain. Therefore, it is important that these companies not only understand the immediate customer requirement but also do a downstream market research until where the supplier product offering is finally used by the consumer in the value chain is required ([19], p. 3).

6.1.3 Problem Statement

As discussed in Sect. 6.1.1.1, Tier-2 Automotive Infotainment System (AIS) semiconductor companies are faced with a derived demand for their products. They need to have a clear understanding of the evolving market trends and be prepared with products even before the Tier-1 companies realize the need. Therefore, the main research problem of the thesis is

How can automotive infotainment systems semiconductor companies, identify future market requirements and promote their products in their downstream market to be a market leader?

The problem statement demonstrates the needs for AIS semiconductor companies to understand emerging market trends in infotainment systems and help the semiconductor industries to develop products that can be served to their immediate Tier-1 customers. This problem is handled by identifying different market requirements through quantitative and qualitative analysis of customer expectations and requirements at various stages of the value chain. The results will help the company to deliver products that can benefit the Tier-1 AIS suppliers. Consequently, the semiconductor companies can then realize a positive impact on customer retention, loyalty and revenues.

6.1.4 Research Questions

The main research problem stated in Sect. 6.1.3 is broken down into several research questions to better understand the context and streamline the process of research. Each question is examined individually by referring to the related literature for existing theories. The following aspects are considered to define the research questions.

- End consumers vary from each other in various dimensions such as education level, income, geographic location, gender and preferences of the car, etc.
- Various consumer needs create market requirement
- Technical advancements make a huge factor in setting consumer expectations and requirements
- In B2B markets, the supplying firms face derived demand for their goods and have strong collaboration with the immediate customers for new product development.

Based on these aspects, the following research questions are formulated.

- What are the end consumer expectations, preferences for automotive infotainment systems?
- What is the outlook for car radio system? Will it be replaced by personalized music and video contents?
- What are the emerging mega trends and their impacts on automotive infotainment system?

6.1.5 Structure of Thesis

The study is divided into five chapters. The first chapter gives a general background of automotive infotainment systems and challenges in the product development. It explains the purpose of this thesis and outlines the research questions. In the second chapter, extensive literature review is carried out on two main topics. Firstly, literature review on the megatrends and their impact on the automotive industry followed by industry specific trends to automotive infotainment systems are reviewed. Secondly, theories related to consumer expectations followed by the literature review on impact of consumer behavior, followed by specific literature to automotive infotainment systems. The third chapter is about the research methodology used and underlying reasons behind the formulation of a survey questionnaire. The fourth chapter is about the discussion of results. Finally, the project work is concluded in the fifth chapter with certain implications, limitations and outlook of the research.

6.2 Literature Review

It is important that the marketing managers understand the importance of the consumer behavior and it gets crucial at times of recession to understand consumer behavior, to be commercially successful. The task of predicting consumer behavior is very difficult even for experts in the field ([20], p. 76). According to Stávková et al. [21] consumer behavior research facilitates not merely understanding the buyer, it enables understanding the consumer motives and forecasting the future product needs. Therefore, it is important that firms understand consumer behavior and implement their needs in their value creation process [22].

In this chapter, study on global megatrend and later to Industry trends specific to AIS are studied. This is followed by reviews of theories concerning consumer preference and the Kano model of customer satisfaction is studied.

6.2.1 What Is Megatrend Analysis?

It is common for marketers to think immediate trends in the purchase of the products or services over brief time. It is also important that marketers understand the emerging megatrends to be prepared for long time sustainable business ([23], p. 354). Therefore, in the following sections, we will see the definition of megatrends, megatrends impacting the automotive industry and the emerging megatrends in the AIS industry.

6.2.1.1 Definition and Characteristics of Megatrends

The term megatrend was coined by Naisbitt [24] in his work to highlight how the mega trends are transforming our lives. The definition for megatrends is given as "Megatrends are structural movements which go beyond local developments and operate in the technological, economic, political, demographic, social-cultural and environmental domains" ([25], p. 19). Moller [26] identifies three main characteristics of megatrends:

- They occur over an extended period usually over decades.
- Megatrends affect and influence every individual's life.
- Megatrends occur globally; however, the impact of megatrends vary for different areas.

Mittelstaedt et al. [27] proposes three social-science constructs for understanding the megatrends. The first construct is that megatrends arise due to a complex interaction of economic, political, cultural, philosophic and technological factors. Irrespective of the origin they create a significant impact across the globe. The second construct is that megatrends are seismic in time and space; therefore it is difficult to control the emerging trends. They occur in and influence all walks of our life without any control over it. The final construct is that residuals of the previous megatrend and current circumstances lead to future megatrends.

Throughout the history certain trends emerge in all fields like economy, technology, politics etc. Some of the trends are noisy while many trends have proven to have create impact on society as whole to every individual [28]. The reason for the megatrends are attributed to two main factors firstly due to aspiration, wishes and speculations among every individual and secondly due to serious information, facts and other data that are available ([26], p. 3). The difference between trends and megatrends is that the trends are usually for abbreviated period and megatrends occur over prolonged period in decades.

6.2.1.2 What Are the Merging Global Megatrends?

Gao et al. [29] identified that IT systems pave way for huge megatrend in the field of automotive industry. With the Industry 4.0 and digital revolution, automotive OEMs are facing a drastic change from their traditional methods and are forced to identify the disruptive trends of the future. According to a report by PwC Modly [30], there are five key global megatrends that affect every industry sector which is discussed in detail below.

Changing Demographics

The demographic shift implies the change in the population structure of a specific economy. Changing demography affects the macroeconomic growth and forces the organization to rethink their business model ([31], p. 249). In economies where the population aging is rapid, the income and the labor power of the economy are affected compared to economies where the growing population which can earn and contribute to the future progress ([31], p. 250) ([31], p. 250). In countries like Germany, where the population is aging or stagnating (change in demographics) and the rise of urbanization leads to lack of interest in car ownership ([32], p. 922). Also, this change in demography to an aging population paves way for emerging mega trends of autonomous driving ([32], p. 922).

Shift in Economic Power

According to Modly [30], due to rapid growth in developing countries and saturating markets in developed countries, companies are keen to look for emerging economies. Furthermore, trade development and interconnectivity are rising rapidly compared to the developed nations making them the next big market powers. Due to rising economic conditions of the societies in China and India, automakers see a huge growth potential in these markets ([30], p. 4). The Chinese markets are poised to have great demand for cars and considering their taste China appears to be a lucrative market for the premium segment for automotive manufacturers. Currently, the local Chinese OEMs are not yet as advanced as those of the developed countries OEM. However, in the future, it is expected that they will grow rapidly and after fulfilling their local needs might expand into other countries [29].

Accelerating Urbanization

According to Modly [30] there will be a large migration of people from rural areas to cities. It poses a great challenge for developed countries and old big cities in the emerging nations to change and adapt to the rapid urbanization ([30], p. 12). Due to the need for more investment in infrastructure and regulatory policies government play a strong role in scrutiny of the automotive sector. Because of the increasing traffic congestion and pollution caused by automobiles, in countries like India the government has already imposed a ban in the city of New Delhi for car commuters to use their car based on odd-even number license plate strategy [33]. All these regulation policies force automakers to consider opportunities beyond traditional market and foster innovation across their value chain ([29], pp. 3–6).

Rise of Technology

Due to continuous development in technology in the field of nanotechnology, biosciences and cognitive sciences possess a large variety of business opportunity. Increasing digitization such as Internet of things, data analytics and artificial intelligence force the automakers to rethink their business model ([30], p. 16). This rapid technology growth aids the “Millennial” thought on ownership. According to ([29], pp. 8–9), Millennials have a high preference towards car-sharing services based on pay as usage. They would like to benefit out of technology, connectivity through smartphone and reduced cost of ownership for their mobility preferences. All these rising needs might pose challenges as well as opportunities for OEMs to re-think their business model. Despite the increasing car-sharing services, Gao et al. [29] predict that the mobility distance per person will not decrease and factors such as wear and tear of existing cars will lead to increase in car consumption but at a slower rate.

Climate Change and Resource Scarcity

According to Pyhäranta [34], European Environment Agency, environment trends are impacted by three subcategories: they are depleting the natural resource, increasing pollution and climate change. Increased usage of resources and fossil fuels makes these resources scarcer. Furthermore, they lead to huge amount of carbon emission. All these are main drivers for the industry to focus on a more sustainable solution and they impact the way the traditional business operates ([30], p. 20). To support the rapid technological advancement, sustainable and renewable power sources are the main topics. In countries like China, where the pollution is heavy, the government has clearly stated its interest in electric vehicles (EVs). In fact, in Beijing, for a person to drive with conventional petrol or diesel engine he has to participate in a lottery and therefore clearly making the conventional engines as an artifact and a luxury to have feature Gao et al. [29]. All these forces the automakers to enter into the electric vehicles market and it is anticipated to be the future. In a report by Godau [35], It shows the consumers have an interest in the electric car if they could charge fast and perform comparable to the Internal Combustion Engines (ICE). Furthermore, the main barriers are high cost and slow battery charge rate. It is also found in the report that offering incentives and subsidizing the electric cars have played a huge role in adoption in countries like China and Norway. Despite the challenging requirements posed by the consumers, they feel that EVs reduce the environmental impact and there is clearly a great interest from the public to adopt EV for public and private mobility in the future.

6.2.1.3 What Are the Industry Trends Specific to Automotive Infotainment Systems?

The infotainment System is seeing a rapid development in the past decades and competing to that of the consumer electronics trend. The AIS industry is influenced by several factors such as rapid growth in semiconductor technologies, need for personalized services, software defined radio, entry of big smartphone makers and software platforms.

Why Do OEM's Partner with Semiconductor Industry?

Clearly, the semiconductor industry has gained a rapid growth due to increasing value of electronic components in a car. According to Abelein et al. [36], the AISs are facing rapid growth and challenges especially from speech recognition, 3D visual processing, and displays which require improved hardware efficiency. Abelein et al. [36], postulates that there is a strong need for clear triangular communication strategy between Tier-1 suppliers, semiconductor providers, and the OEM to achieve high-quality reliable infotainment systems. Understanding the importance of the triangle communication, big OEMs like Audi have initiated a program like Progressive Semiconductor Program (PSCP) ([37], p. 13). The PSCP program aims at building a strong partnership with semiconductor industry to promote research and innovation, to have reduced design life cycle and can operate efficiently like that of the Consumer Electronics Industry. Also, the program ensures quality and foster research and development alongside the rapidly changing market requirements faced by the OEMs.

How Does Software Defined Radio Influence the Infotainment Market?

The automakers are seeking constant opportunities to expand their car sales into different markets. This makes them globally present in many countries. The main challenge here is the car production happens in a specific country and the car is not necessarily sold in the same country. Therefore, a complex situation arises, because of different radio receptions present in different countries. Especially with the increasing trend of digital radio every country has its own frequency for radio reception and the broadcast technology also varies [38]. Therefore, in order to overcome this problem automakers prefer a technology called Software Defined Radio (SDR) in the infotainment applications, where they can control the decoding of the radio reception based on the software [39]. This strategy helps them to overcome the barrier of hardware limitation to each radio reception standard. As an example of the situation, a car being produced in countries like India uses Digital Radio Mondiale (DRM) as its digital radio standard. However, the car may not be sold in India and gets exported to Europe, where the radio reception is DAB or DAB+ standard. In such a case, the automakers simply flash the Digital Audio Broadcast (DAB) or DAB + firmware into the infotainment for radio reception without having to change the hardware for each car.

What Are the Ongoing Competitions in Software Platform?

The AIS has undergone rapid changes over time. Although the Navigation and Radio systems have been present for a long time in AIS, Ford and Microsoft were the early recognizers of the need for integrating the consumer digital life style into AIS ([40], p. 99). The result of such a collaboration was the Ford SYNC. Later, all the automakers took over this idea and came up with infotainment system software platforms based on Microsoft's Embedded Automobile System or Blackberry's QNX software platform ([41], p. 19). According to Greengard [41], the early infotainment platforms lacked vibrant voice recognition features and were complicated and too clumsy for the consumers to use. Having understood the problem here, smartphone giants like Apple and Google who already have an adequate smartphone user base, released Apple CarPlay and Google's Android Auto to make supplementary in-car entertainment systems ([42], p. 598). The main reason for the success of these smartphone giants in AIS markets is that consumers want to experience all the contents they get on their smartphone with same displays and interfaces that they are familiar with ([41], p. 18). Companies like Google, Apple, Baidu and Amazon all are trying to enter infotainment space so that they could gather data related to driver's behavior and other car-related information which could be of use directly or to third parties. Because of these easy-to-use and familiar Human Machine Interface (HMI) consumers can operate different cars but in an easy and standardized way ([41], p. 19). Both the Android Auto and the Apple CarPlay are proprietary software prohibiting the OEMs to make any alterations, thus making the automakers lose power over the infotainment software. OEMs are making their own software platforms for creating an ecosystem around a car environment [43]. For example, Ford with SYNC, Toyota with Entune, Nissan with Nissan Connect, Daimler with Mercedes Me, etc. are all independent software platforms from the automakers.

Amidst fierce competition, several open-source platforms also find their way such as GENIVI and Automotive Grade Linux (AGL) which are focused on making the platform more open source and standardized among the automotive manufacturers. Klavmark and Vikingsson [44] investigate different open platforms that are available currently for infotainment applications and they find in their research that GENIVI is most likely to succeed soon considering the backup by a strong alliance in the open-source platform. Also, the AGL platform is also found to be making debut in the market with Toyota Camry being the first adopter of the AGL platform [45].

How Do Personalized Services Personalized Services Change the Future of Car Infotainment?

There is a strong growing demand for personalized apps and entertainment needs. From the consumer behavior point of view, research by Tansik and Routhieaux [46] has shown that music can influence the stress on a human. It can make them feel relaxed. Alam [47] analyzes the trends for the connected car and identifies that all the services offered in a car are getting highly personalized. Personalized apps, music and on-demand content streaming, context-aware systems have an immense potential in the future market. Furthermore, the automakers not only have to invest in technologies to offer personalized content experience; there is an enormous potential for bundling of services by understanding the driver preference. In an interview with Thimmappa [48], Mr. Prahab Deivanayagham Senior director of the connected car at Harman has said that the smartphone penetration and strong ecosystem for app developments have pushed the car consumer into downloading personalized contents. He also claims that the space for app store has already been taken by the silicon giants such as Google and Apple through their Android Auto and CarPlay respectively. There is a strong need for music applications like Spotify, Auto Navi and other apps that are offered in the smartphone environment to be integrated into the AIS.

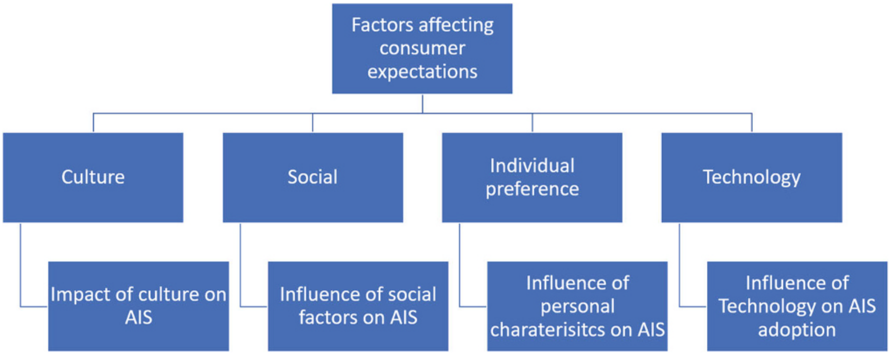

Fig. 6.1 Structure of literature review on consumer needs (own depiction)

6.2.2 *What Are the Factors that Affect Consumer Expectations from Automotive Infotainment Systems?*

Driving is a complex and tedious task that requires uninterrupted attention and coordination of physical, mental, sensory and psychomotor skills ([49], p. 379). There are several reasons for driver distractions leading to accidents ([50], p. 1). According to Stutts et al. [51], driver distractions are caused due to cell phone usage, infotainment controls, etc. Therefore the main purpose of in-car entertainment is to not distract the drivers and at the same time offer certain entertainment to keep them engaged while driving (La [50, 52]). Apart from this, there are numerous factors from related studies that are grouped and discussed in this section under four categories: cultural, social, technology and self-concept. Figure 6.1 shows the structure of the literature analysis carried out based on factors and their influence on AIS.

6.2.2.1 How Do Cultural Factors Influence Consumer Expectation?

Hofstede [53] defines culture as "The collective programming of the mind which distinguishes the members of one category of people from another" ([53], p. 1).

The cultural background of the consumer has an enormous impact on consumer behavior and its importance is growing in consumer market ([54], pp. 163–164). Therefore, it is important to consider the cultural role in consumer behavior and buying intentions.

What Are the Impacts of Culture on Automotive Infotainment Systems?

Several studies have highlighted the importance of culture on designing Human Machine Interfaces (HMIs). In a study conducted by Lindgren [55], to understand the impact of culture in the design of Advanced Driver Assistance Systems (ADAS) between Chinese and Swedish drivers. It was concluded that it is problematic if culture aspect is eliminated in the ADAS design and Chinese drivers need an adapted version of ADAS considering the driving behavior [55]. A study conducted by Young et al. [56] aims at highlighting the cross-cultural difference in IVI requirements between Australian and Chinese drivers. The study showed that Chinese drivers opted for a highly aesthetic look of the HMI and placed less importance on safety and driver distraction, compared to Australian users. Also, Chinese drivers were not able to understand the abbreviated text in the HMI system compared to Australian drivers ([56], p. 571).

Furthermore, studies show that Chinese drivers can perform simultaneous tasks and therefore require a large amount of information being available to them and prefer greater speed in screen formation, as compared to German or English drivers ([57], pp. 375–376). Another study conducted by Khan et al. [58] focuses on a cross-cultural study between UK and Indian users' HMI preference. It was found that navigation systems and vehicle blue tooths designed for UK drivers' capability for information decoding and visual appeal created a negative impact on the Indian drivers to access the system. These results were measured based on task completion times and error rate. Furthermore, the study concludes that the features that are not a "must-have" feature for UK market are viewed as "must-have" or attractive features in the Automotive HMI systems in Indian market ([58], pp. 59–60). From all these literatures reviewed so far, culture plays a huge role in customer requirements and it is highly important to keep in mind the impact of culture on automotive infotainment systems design and purchase behavior.

6.2.2.2 Why Do Social Factors Play an Important Role in Consumer Expectations?

Social influences are the extent to which members of a society influence the behavior of another member [59]. Burnkrant and Cousineau [60] in their research find that social influence has a significant impact on the buyer's behavior and requirements to products. Social influence on a buyer can generally be referred to as conformity to a group where the buyer tries to reduce the dissonance of the situation ([61], p. 100). Building on this concept of groups, Kotler and Armstrong [62] identify two such types of groups: membership groups and reference groups. Membership group refers to a group that a person belongs to and this has a direct influence on the person's behavior [63]. Reference group serves as a point of comparison for a person who aspires to be a member of such a group. They may or may not have a direct influence on the person. Reference group exposes a person to new behaviors and lifestyles unknown to the person before ([64], p. 341). This is extremely important for marketers who try to influence a person through different reference groups and affect the person's product or brand choices ([62], p. 239).

According to Silvera et al. [65], consumer susceptibility to interpersonal influence is determined by two dimensions: informational and normative component. An informational component refers to individuals actively seeking for information about products or services before buying them. The normative component refers to individuals need to buy a product for enhancing his social image or conforming to the expectations of others in buying decisions. It is human tendency to strive to be accepted as a part of society. Therefore, their actions are seeking towards them being accepted in a social group ([66], p. 256).

According to Kelman [67], the social influence occurs in three ways: compliance, identification, and internalization. Compliance refers to the acceptance of influence by an individual, where he accepts or conforms to the expectations of an individual or group, to obtain a desirable reaction. This favor enjoyed by the complying individual could be avoiding punishment or receiving a reward ([67], p. 62). Internalization occurs when an individual accepts social influence, by which the person perceives this as a congruent behavior to the system. In other words, the individual perceives the change in behavior could lead to the achievement of the goal in the system ([67], p. 65). Identification takes place when an individual adopts an opinion or behavior as a response to the behavior that is associated with a self-defining relationship to a person or group. Influence through identification helps in maintaining the self-image that a person has a relationship with another person ([67], p. 63). Bang et al. [68] suggests that individuals consider the other person or group thoughts about his action, before indulging in them. Thus, the social pressure influences a person's behavior.

How Does the Social Factors Influence the Consumer Expectations on AIS?

A study conducted by Stave et al. [69] treats ageism as one of the social factors and they try to understand the needs and requirements to be considered for old drivers. It was identified the social needs of old drivers and developed are commendation system to design Advanced Driver Assistance Systems. In another study conducted by Hiscock et al. [70], identifies the psychosocial impacts of possessing a car for autonomy, prestige, and protection. Knobel et al. [71] in their research identify the social needs and propose a model for creating a positive social experience in the car, by means of Clique Trip. According to safety guidelines in the design of automotive HMI design by focus-telematics [72], radio tuning is used as the suggested primary test. In a research by Perez [73], the socially acceptable distraction when driving a car is identified, and the safety implications on infotainment systems design is addressed. A study was conducted to identify the social dilemma of an autonomous vehicle by Bonnefon et al. [74] according to whom the social regulations are to be enforced by the government and people are not willing to adapt their behavior. They also argue that the total utilitarian value should be high if everyone adapted to autonomous driving. According to Waytz et al. [75], it has become a social culture for people to rely heavily on infotainment systems for driving directions and keeping themselves entertained, rather than asking or talking to people.

6.2.2.3 Why Do Socio-Demographic Factors Influence Consumer Expectations?

According to Buente and Robbin [76]), the socio-demographic factors play an important role in informative or entertainment usage. Alcántara-Pilar [77] suggests that socio-demographic factors such as age, gender, household income, education level, race and ethnicity all play a significant role in purchase behavior of consumers. In a research conducted by Howard et al. [78] they find that different socio-demographic groups seek different Internet content behavior. They find that content-seeking behavior varied with age, gender, income and ethnicity of people. Also, it was identified that a customer's motivation to buy is influenced by demographic characteristics of the buyer. Kotler and Armstrong [62] explains the concept of consumer life-cycle stage to marketing explains the changing customer requirements over time. Therefore, marketers must capitalize the changing demand and develop appropriate products. Since demographics of consumer vary widely between different buying situations, a general rule cannot be determined across all industries. Hence marketers in different industries use known heuristics to segment market based on demographics.

6.2.2.4 How Do Socio-Demographic Factors Influence the Consumer Expectations from Automotive Infotainment Systems?

In a study conducted by Stave et al. [69], they identify the needs for AIS for old car drivers. It was shown that the old people care for more respect and easy-to-use interface with the technology that they are familiar. Also, the modern technologies create anxiety and stress on their driving performance. In a study conducted by Lee [79], it is found that young drivers are highly affected by the infotainment technologies leading to more distractions and accidents. Also, the research finds that the young drivers are more open to technology compared to experienced drivers.

In a survey conducted by Schoettle and Sivak [80] about self-driving cars in UK, USA and Australia, used gender, age, driver's education, type of employment and type of car driven as the socio-demographic variables. In the study, it was found that in general, female respondents found the benefit of autonomous cars is more less likely. It was also shown in the study that the young drivers are most likely to use driver assistance compared to old people. The entertainment value expected in a car according to the study was less, while the survey showed that people will be more cautious and still be watching the road for a crash in a self-driven vehicle.

In another study conducted by Sha et al. [81] they showed that Chinese women are more open to premium and niche products and they have a strong interest in owning a small car with many functions compared to large cars. According to Gao et al. [29], millennials do not want to own their own car and are willing to use technology for car sharing and ride sharing services. They expect more personalized contents and services compared to other age groups.

6.2.2.5 Why Does Individual Factors Play an Important Role in Influencing Consumer Expectations?

The consumer purchase behavior is highly attributed to the individual self-concept and the identity of the product, that is, the brand, usefulness, and value that is involved in purchasing [82]. Consumer-buying individual factors is complex and involves numerous factors grouped as lifestyle, motivation, perceptions, and personality [83].

Lifestyle

The lifestyle of an individual goes beyond his social class and personality by the way of personal profiles that are interacting in the environment ([62], p. 146). According to Ghangurde [40] a consumer's lifestyle is highly influenced by digital technology in communication and entertainment markets. This lifestyle forces the AIS manufacturers to adapt the technologies quickly and be up to date as in consumer electronic goods. A market research conducted by Microsoft along with FITCH indicates that the need for safety, music and navigation is increasing. It was also observed by Microsoft that consumer requirement for smart connectivity is strongly growing due to the lifestyle influence ([40], p. 100).

Motivation

According to Ryan and Deci [84], Self-Determination Theory (SDT) was introduced to analyze the reasons and intended goals towards certain activities. The SDT classifies two types of motivation as intrinsic and extrinsic motivation. When people engage in an activity voluntarily due to self-interest and enjoy the actions it is called autonomous or intrinsic motivation. This is due to fact that the people are not forced or controlled to be involved in an action. On the other hand, when people are subject to control or forced into performing a certain action it is called controlled or extrinsic motivation ([85], p. 334). Thus, in simpler words, it can be inferred that intrinsic is the internal force that drives an action and extrinsic is the external pressure leading to certain action. When people experience positive feeling, it leads to a positive effect on intrinsic motivation and if they experience negative feeling it has an adverse effect on motivation.

Yalch and Brunel [86] suggest using Maslow's theory of motivation to understand the consumer needs and to product design and characteristics. In the study, it was shown that the consumer needs are the fundamental motivation involved in product purchase. Depending on the level of needs that are satisfied, consumers motivation varies from bottom to top of Maslow's pyramid. Therefore, it is the purpose of the marketer to understand the motivation of the buyer and convey it to them.

Perceptions

Zeithaml [87] identifies the consumer perceptions involved in purchase decisions attributed to three main factors such as perceived price, value and quality. Perceived quality is the level of excellence or superiority offered by the product or service as judged by the consumer. The objective and the perspective qualities are different in the sense that objective quality is verifiable to the characteristics of the product. The perceived quality is the subjective interpretation of the quality of the product by individuals ([87], p. 4). Extending the concept of perception, Chang and Hsiao [4] conducted a research on consumer intentions in buying a car based on the perception of value from the infotainment system. According to Chang and Hsiao [4] perceived value is the consumer's judgment of car infotainment system based on the perceptual benefits he receives to the sacrifice that needs to be made involved in car purchase given as

$$Percieved\ Value = \frac{Percieved\ Benefits}{Percieved\ Sacrifice}$$

Perceived benefits have two components as shown in the model. Davis [88] developed Technology Acceptance Model (TAM) and coined the term perceived usefulness in this model. Perceived usefulness is the benefit that some beliefs to enjoy on adopting the IT systems. If the consumers perceive that the technology used in the systems prove to enhance the safety of driving function then it is termed as perceived driving safety. For example, in an automotive environment, there are features like night-driving assistance or belts or airbags that improve the perception of safety functions and increase the value of the product to consumers ([4], p. 4155).

Perceived sacrifice involves two major components. Perceived risk is the customer view of risk involved due to their behavior leading to unforeseeable or detrimental outcomes [89]. When consumers must pay price for the product they make a financial sacrifice leading to reduced value of the product. All the perceived benefits components lead to positively perceived value on the consumer perceptions and all the perceived sacrifice components lead to negatively perceived value on the consumer perceptions [4].

Zheng et al. [90] conducted a research to understand the subjective appearance to perceived usability of car infotainment systems. The study was done by using 15 different infotainment systems images and was made to evaluate by experts of HMI design. It was found in the study that the subjective appearance had an influence on the perceived usefulness. Also, a more professional and organized interface design will increase the perceived usefulness of the infotainment systems ([90], p. 544).

Personality

Personality is a self-concept that refers to the characteristics that an individual possesses which distinguish him from others ([62], p. 146). Personality is not the same as the cognitive aspect or an individual's abilities and skills. It is explained by the concept of Traits ([91], p. 147). The influence of consumer personality on buying behavior was explored by Evans [92]. The research was focused on understanding, the choice of the car a consumer makes between Ford or Chevrolet reflecting on the individual's personality. However, there was no sufficient data sample to prove the hypothesis.

Research conducted by Kuehn [93] demonstrated that affiliation and dominance were two dimensions that could be used to predict the personal characteristics. Westfall [94] studied the personality difference among the owners of standard, compact and convertible cars. The study was based on Thurstone's Temperament Schedule to measure seven characteristics such as active, vigorous, impulsive, dominant, stable, sociable and reflective ([94], pp. 35–36). The study found that there was no significant personality difference between standard and compact car users. However, the convertible owner's personality was different from others. The convertible owners were more sociable, active, impulsive, vigorous and dominant compared to other car owners ([94], p. 37).

Sha et al. [81] conducted research about the Chinese premium car market and found that the middle-class people have an ardent desire to buy premium cars, as cars stand for the social status reflecting their values and personality. The study also suggests that to be successful in the China premium car market automakers must have high-end infotainment systems and other driving assistance systems.

6.2.2.6 What Are the Theories that Explain the Influence of Technology on Consumer Expectations?

Technology plays a vital role in consumer purchase intentions. To understand the acceptance of the technology and the intentions behind purchase decisions Theory of Reasoned Actions (TRA), Theory of Planned Behavior (TPB) and Technology Acceptance Model (TAM) are widely used in the literature.

Theory of Reasoned Action

The Theory of Reasoned Action (TRA) was developed to understand consumer behavioral intention by Ajzen and Fishbein [95]. TRA is a cognitive model that is used to address the core issue of why consumers are willing to engage in a certain behavior ([96], p. 124). Because of its high predictability, TRA is used by marketers to understand the consumer behavioral intentions and behaviors ([96], p. 125).

According to Gentry and Calantone [97], attitude towards a behavior is most likely due to the buyers favorable or unfavorable reaction (evaluation, appraisal, etc.) for a given behavior. Normative beliefs consider the element of being approved or disapproved by referent persons or groups on exhibiting a given behavior. Bang et al. [68] suggest that every individual evaluates the various consequences for his decision and considers all the available course of action to him before engaging in a certain behavior. Individuals are said to favor behaviors (i.e., believe inactions), that have desirable outcomes for them. Madden et al. [98] describe that the beliefs held by an individual can be divided into two types namely, behavioral beliefs and normative beliefs. Behavioral beliefs are thought to be the root cause of a person's attitude towards performing a behavior and normative beliefs are thought to affect the subjective norms influencing a person to perform a behavior. However, the TRA model is suited only for volitional situations where the behavior is predicted by intentions. Therefore, the TRA will be a limited to situations where a person has a control of the action he is willing to perform ([99], p. 1174).

Theory of Planned Behavior

The Theory of Planned Behavior (TPB) [100], is an extension of the TRA which can handle the TRA's limitation in dealing with consumer behavior with nonvolitional control ([99], p. 1175). Like TRA, the main antecedent for behavior is the intention of an individual. The intention is presumed to capture the motivation of a person, the effort extended and the will power of a person towards the behavior ([100], p. 181). According to ([101], p. 42) in addition to *subjective norms* and *intentions* to perform specific actions, TPB includes another construct to predict behaviors that are nonvolitional called *perceived behavioral control* (PBC). Paul et al. [96] state that there are three predictors to intentions: attitude to behavior, subjective norm and PBC. Madden et al. [98] claim that the PBC is the extra variable that is added to TPB which has a direct impact on the behavior and also an indirect impact on the behavior through the intentions. Madden et al. [98] suggest that the direct effect of perceived behavioral control over the final behavior has two types. First is that when there is an element of nonvolitional control on the behavior and second is when the perceptions of an individual's control accurately match with the person's behavior. It is clear that few researchers believe that TPB can be used to model the technology acceptance or rejection by consumers considering their decision making and behavior.

Technology Acceptance Model

Technology plays a very big role in the consumer behavior. The adoption of new technologies by consumers was modelled using Technology Acceptance Model (TAM) introduced by Davis [88]. TAM is widely used for technology influence on consumers, their willingness to adopt or reject technologies ([102], p. 244).

The TAM is yet another adaptation of the theory of reasoned action, widely used in the field of information systems to model consumer behavior [102, 103]. Davis [88] developed this theory to explain the computer acceptance among users.

The original TAM had four variables to determine the adoption rate of technologies. The theory introduces two perception variables namely, perceived usefulness and perceived ease of use. Perceived usefulness is belief of a person about the usage of the product and significant improvement in the performance experienced by the user. Perceived ease of use identifies the amount or extent of effort needed to use a product or service ([88], p. 320). The other two variables are attitude towards use and behavioral intention towards use. However, According to Hong et al. [104], TAM only predicts the adoption of technology, but does not provide a means to find the continued usage of the technology.

How Does the Technology Factors Influence Consumer Expectations from AIS?

The Information and Communication Technology is growing rapidly. Consumers have adapted to high smartphone and computer usage. Therefore, they expect the same features to be present in the AIS [5]. Osswald et al. [105] suggest that Technology Acceptance Model cannot be used directly to assess car environment because it doesn't use contextual information. So, they proposed three issues that need to be addressed in the context of a car. Firstly, the information system is contextual, that is, related driving speeds, fuel level and other assisting information. Secondly, the driver is faced with constrained space for accessing interface, and further, it is complicated by the driving and moving environment in the car. Thirdly, the assistance systems create anxiety among people as they need to be more reliable. This model can be used to assess the technology acceptance of consumer in the car, considering the moving environment, anxiety. Another study by Bennakhi and Safar [106] explores the usage of voice control system in a car. It is suggested that the voice control might not be a workable solution in the car, considering the noisy environment around and the development of the technology itself is not reliable yet. The technology that is inside is lagging compared to what is expected by the driver. Reinstating this author claims that "... the point where the driver does not even have to touch his smartphone while driving seems a bit of a far cry" ([106], p. 1060). In another study conducted by Aziz [107], it is found that the technology anxiety causes people to lose trust on the brand. Also, brand loyalty can be increased by lowering the technology anxiety among consumers. Pakusch et al. [108] find that technology has played a huge role in shifting the consumer behavior from ownership to usership attitude. This change in attitude also puts a huge demand in consumers to stay connected to each other via highly secured networks. Thus, the digital technologies are highly adopted by the consumers and they pave way for megatrends—such as car sharing in the automobile sector. The age of the target market places a huge role in marketing. Millennial or Generation Y people have a lot of difference in their attitude and have grown in an era of social media and digital technology. They have high expectations and require more variety for low cost [109]. Especially in countries like China, where the smartphone adoption is very high, people use "Autonavi" a Chinese app which is much accurate and exceeding voice-driven capabilities compared to automaker-installed infotainment systems. This puts a large pressure on the car OEMs to succeed in the premium Chinese car market ([81], p. 11).

6.2.3 Kano Model of Product Requirements

Kano [110], proposed the Kano model which has three attributes to specify the product requirement in meeting the customer satisfaction. First are the *must-be requirements*. These comprise the basic criteria that the product is supposed to fullfill. Not having these features will lead to dissatisfaction and any innovations that are made on top without meeting these *Must-Be Requirements* are not successfully received by the customers. These feature requirements are not explicitly stated by customers but inherently expected to be met ([111], pp. 30–31).

The second attribute to the Kano model are the *one-dimensional requirements*, that are explicitly demanded by the customers. It refers to direct fulfillment of requirement, which is proportional to the satisfaction. More these requirements are fulfilled the satisfaction increase and the vice versa holds ([111], pp. 30–31).

The third attribute comprise the *attractive requirements*, which is a highly influential factor on the customer satisfaction level. The features of this are not explicitly stated and expected by the consumer. Therefore, this is highly optional, in the sense that not fulfilling it will not create dissatisfaction. However, the more attractive the features are to the customer the more they highly differentiate the product and have an exponential influence on customer satisfaction. These features enhance the perceived value and satisfaction of the customers.

There are two other attributes, *indifferent quality elements* and *reverse quality elements*. While the features of the former are those that do not change any satisfaction level irrespective of whether the features or added or not, the latter refers to inverse proportionality with fulfillment of features ([112], p. 2).

In general, the Kano model helps the product developers to understand the product requirement by understanding the product needs faced by customers hence improving the satisfaction of customers. Since product requirements differ for different customers, the three Kano attributes discussed guarantees in increasing the utility expectations of all the customer groups ([111], p. 30). Shukla et al. [113] have used the Kano model integrated with Quality Function Deployment (QFD) for passenger cars and have highlighted the benefits of this combination.

Thus, the literature concerning the concept of megatrends and their impact on the automotive industry was review followed by industry specific trends for AIS was reviewed. Furthermore, consumer behavior theory and the factors behind consumer expectations and product requirements for automotive infotainment systems were reviewed.

6.3 Research Methodology and Theoretical Framework

The main aim of this chapter is to elaborate the conceptual development of the research framework adopted to perform this study. This approach helps to outline the strategy that needs to be taken to achieve the goal of the thesis. Different research methodologies that are widely used in the context of marketing are discussed. This is followed by elaboration of how the research was performed along with the underlying reasoning are explained. Finally, the sample size and the statistical properties of the collected data sample are explained.

6.3.1 Overview of Research Methods

6.3.1.1 Qualitative Research

Exploratory studies are a first step in research, which helps to identify if the actual research problem is important. This also helps to save money and saves further human effort if the problem itself is found to be not so important. Primarily, the exploration studies rely heavily on qualitative techniques. Qualitative techniques involve conducting interviews with experts in the field to understand their perspectives difficulties and to gather their opinion on emergence of the research topic itself. Therefore it can be seen that the primary goal of qualitative research is to understand the perspectives of the experts in the way they experience in reality [114]. According to Blumberg et al. [115] the literature search and expert interviews are the two most extensively used exploratory research techniques.

6.3.1.2 Quantitative Research

Most empirical studies involve the quantitative research technique which involves collection of data ([116], pp. 1139–1140). To collect he data questionnaires are developed, to gain the perspectives, intentions, to analyze the underlying trends and also to find the consumer requirement [117]. The questionnaires are sent to be distributed and filled in by a target audience. The filled response serves as the basic data for the research analysis.

The questionnaires developed can be open ended to answer, the audience can answer each question with their own text. This provides more insights and the text rich answers allowing the responder to describe in detail ([118], p. 831). Another type of questionnaire is called close-ended questionnaire. In this approach each question is given with all possible answers that are to be given and typically the user is expected to choose one of the options for each question.

According to Baruch and Holtom [116] both the techniques have their own advantages and disadvantages. The advantage of the open-ended questionnaire is that they help to gather more information and honest feedback by keeping anonymity of the response. However, the biggest problem is analyzing the text rich response for hundreds and thousands of responses. An open-ended response also faces the subjective interpretation problem of the research ([118], pp. 830–831). A close-ended questionnaire overcomes this problem as the audience are only allowed to choose only options for questions. This makes the analysis much easier and make use of statistic techniques. However, it faces a problem if the options are not sufficient and the responder has something else to answer. Thereby it limits the amount of information that can be potentially gathered. In formulating a close-ended questionnaire the researcher should think of all possible answers and must be easily understood by the target audience.

6.3.1.3 Methodology to Identify Product Requirements

There are several methods applicable to identify product requirement of consumers. Griffin and Hauser [119] highlight the facts that nearly 20–30 customer feedbacks on homogeneous products are sufficient to determine 90–95% of all the requirements. It is important to dig deeper into customer problems rather than just looking merely on their desire ([111], p. 31). Cooper and Dreher [120] has categorized different techniques that are used for finding out the Voice of Customers (VoC). In this study, a survey is carried out to identify top product requirements of infotainment system.

The second most crucial step is to construct questionnaires that require response from the consumers. Questions should focus on the underlying usage pattern, customer wishes, their usage pattern and preference to deeply understand the problems faced by them. It is important in formulating such questionnaire where the technical solutions are not being addressed directly to consumer. This has two advantages: the first is that responder can understand and perceive the benefit of product solution and secondly, it also doesn't restrict the creativity of engineers in offering solution to the problem faced by consumer in the product ([111], p. 31).

After the questionnaire is prepared, the questions should be targeted to consumers who are potential target of our product usage. When questionnaires are asked to be filled by consumers directly, it is cost efficient as it involves using digital media. However, since consumers need clarity on understanding and avoiding misinterpretation explanations are to be provided to consumer. The data are collected and finally analysis is performed.

6.3.2 Developing Questionnaires

A questionnaire is a standardized framework which contains a series of question and possible relevant options and scales that respondents can fill with answers they perceive are right. The construction of a questionnaire comprises of established measurement scales such as Likert scale and using them as an aid by the respondents to communicate information, which serves as collected as raw data for further analysis. The questionnaire developed for this thesis consists of our main topics and questions that require response under them.

6.3.2.1 General In-Car Entertainment Requirement

This section is about general in-car entertainment sources and features for passengers. It is important to understand the usage pattern and preference for in-car entertainment among the passengers. People travelling in a car, both the driver and the passengers resort to some source of entertainment in the car. Some of the entertainment sources are listening to music via radio and personalized music contents for drivers and passengers. However, other sources of entertaining activities are magazines and newspapers and web browsing, which applies primarily to the passengers and not to drivers. Furthermore, it is important to understand how the drivers or the passengers like to play the music content from the infotainment system. There are several sources for playing music in a car ranging from radio, CD/DVD players, USB stick, mobile phone streaming and Internet streaming ([121], p. 452). Additionally, virtual reality gears are seeing high penetration in the consumer market. However, the problem of virtual reality is that it cannot be used for moving vehicles as it leads to motion sickness [122]. Hock et al. [123] have proposed a car VR for entertainment in car. Furthermore, social networking plays a huge impact on our day-to-day life, such as Facebook, WhatsApp, etc. [124]. Considering all these factors the following questions are formulated:

Q1: What are the primary sources of entertainment in a car?
Q2: How do users prefer to play music or video contents in future cars?
Q3: Which infotainment functions are to be present in future cars?

Interacting with the system consists of controlling or giving input to the system and display features. Ng et al. [125] has studied the impact of various input controls on infotainment systems for button, knobs and dials over the driver distraction. Studies conducted by Pickering et al. [126], Parada-Loira et al. [127] have shown the usefulness of hand gesture control for car infotainment systems. Furthermore, voice assistance technologies are seeing rapid development with artificial intelligence and speech recognition advancements which are rapidly finding their way into the infotainment systems [128]. Infotainment system are packed with lots of technologies and information, so careful selection of vital information and presenting to them is a key aspect ([129], p. 41). There are various display technologies such as flat display screens, curved display screens [130], 3D display screens [131], Heads Up Display (HUD) [130] and augmented reality [132] for cars. Therefore, it is important to study which of these technologies are most expected by the consumer; hence the following questions are formulated:

Q4: How do users prefer to control their car infotainment system?
Q5: Which display features are expected in their car?

Meschtscherjakov et al. [133] propose classification of car into three regions, driver area, front area and area for studying the infotainment features. Car infotainment systems can be a single system or it can include offering separate entertainment for each passenger. In the case of single entertainment only one system is present and all the passengers and the driver have to use the same system. Due to legal requirements and practical distraction all the entertainment features such as reading, gaming cannot be made available as they distract the drivers ([133], pp. 105–106). So, it is important to understand the willingness of the consumer to purchase cars with single common entertainment system or individual entertainment experience in a car.

Q6: Do users prefer single common entertainment or individual entertainment systems in a car?

Hsiao et al. have studied the purchase intention of car based on the significance of infotainment features. Rebuilding the idea, it is important to identify the influence of automotive infotainment features on car purchase decisions. So to get subjective opinion to rank feature importance, a five-point Likert scale is used in this thesis [134]).

Q7: How important are the infotainment system features, when you decide to buy a new car?

6.3.2.2 Analysis of Car Radio

In this section consumer preference for radio listening and the features they expect to have while listening to broadcast radio is studied. Broadcast radio has been a popular source of entertainment in a car ever since the introduction of the car radio by Ford in 1922 ([135], p. 233). One of the major problems with radio communication devices are the availability of frequency [136]. So different radio standards are being adopted around the world, such as AM/FM radio, and new digital radio standards such as HD radio, DAB and DRM [38]. As a first step in product requirements for radio listening, it is important to understand the underlying reason of radio listening in a car. La Reyner and Home [52] have studied the effect of radio listening in keeping the drivers from sleeping during driving. Furthermore, there are several studies that has been carried out in understanding the effect of radio listening in car [51, 72]. However, in this thesis the focus is kept on finding out the underlying reasons that attract radio listening in car over personalized entertainment content.

Q8: What are the underlying reasons behind car radio listening over personalized content?

Because of the continuous improvement in the broadcast radio reception technologies and new radio standards, several features and benefits can be offered to consumers [137, 138]. Several features such as background scanning, live recording, display of program name and traffic information are available through broadcast radio reception [139]. Additionally, it is important to understand where do users listen to radio, so that in areas of weak coverage, Broadcast radio listening can be combined with Internet blending to ensure seamless reception [140]. Therefore, following questions are asked to understand what features are important for the users:

Q9: What are the important radio features users would like to have in car radio?
Q10: Where do users prefer to listen to broadcast radio in car?

According to Phan and Daim [141], Mobile services are widely used for music and video applications. Therefore, with high penetration of smartphones it is still a matter of economic value to consumers to adopt smartphone with Internet ([142], p. 2925). To understand whether the Internet streaming will replace broadcast radio applications, following question is framed.

Q11: If Internet is present in the car, will there be a for need broadcast radio?

6.3.2.3 Impact of Sharing Economy on Automotive Infotainment System

Due to the rapid growth and condensation of people around cities "Urban Mobility" is an important topic being discussed around the globe ([143], p. 276). According to Zenobia et al. [144], new artificial markets are developing due to problem with parking and traffic management in smart cities. Dias et al. [145] classifies broadly car sharing in to three forms. First is the car sharing, which is usually within the city limits where people can rent a car for short hours and drop them where they want to. Best examples for this are "Car to go" and "Drive now" business model. Second is the car rentals, usually done for over a complete day or for long distance travels. Some of the best examples for this are the "Sixt" and "Europacar". The third form of sharing economy is the ride sharing or carpooling, where often a ride is shared by multiple passengers who are planning to travel to the same destination. Since in this thesis, the focus is on cars it is important to understand the impact of these emerging trends and how infotainment systems can help in these business models. In order, to understand the consumer preference for future mobility and understand the underlying intentions following question are framed:

Q12: What are the single person, future mobility based on distance they want to cover?
Q13: When do consumers use car-sharing service?

Bellos et al. [146] have discussed about the product lines and business model surrounded by the car-sharing economy. However, in this thesis it is important to understand the user expectations in a car-sharing model. So, the following questions were formed to understand the user preference:

Q14: How do users prefer personalized entertainment experience when using a car sharing or rental service?
Q15: What infotainment features are important when choosing a car sharing service?

6.3.2.4 Impact of Autonomous Driving on Automotive Infotainment System

Autonomous driving or self-driving vehicles are a popular topic that are looked on as a solution for future mobility to overcome traffic congestion [143]. Autonomous driving itself comes in five different levels ([80], p. 2). In this thesis, it is of utmost interest to deal with level 4, where the vehicles are completely autonomous and managing all the safety critical features. It is of importance to understand the adoption of autonomous driving and focus on services that the consumers might be interested to avail in the new extra time they have while travelling in autonomous cars. This question is crucial to understand the importance of entertainment value in the car for future markets:

Q16: *What are the reasons people wanting to adopt self-driving cars?*
Q17: *What do the consumers like to do in the newly found free time in an autonomous car?*

6.3.3 Survey Methodology and Data Collection

The questionnaires which were discussed in Sect. 6.3.2 were deployed for survey using Google Forms, a web-based tool for survey deployment. The survey questionnaire is shown in Appendix. The survey was shared online over social media such as LinkedIn, Facebook and via E-mails to reach the respondents. The survey was designed as self-explanatory. The first section consists of the purpose and a brief introduction to respondents about the topic of survey. The language of the survey was in English. Also, there were no incentives provided for the respondents to fill the survey. Details about the respondent's gender, employment status, residential region and type of the car they own were collected for analysis.

The total response of the survey was 376 out of which two responses were uncomplete making it not useful for the analysis. Therefore, 374 responses are eligible for the analysis. The marginal error rate for the total result is ±5.07% with 95% confidence interval. The marginal error rate for countries are India is ±6.9%, Europe: ±8.4% and North America: ±20% at 95% confidence interval.

6.3.3.1 Profile of Respondents

The nature of the data collected is majority from India and Europe. Other regions apart from India, Europe and North America are categorized into "Others." In order to understand the profile of the respondent from each region cross-tab analysis was performed. Table 6.1 shows the cross-tab analysis of gender-region. It can be seen that over all male respondents (74.3%) were higher compared to female respondents (25.7%). As seen from Table 6.2, The majority of the respondents were 18–30 years

Table 6.1 Gender-region cross tab analysis

			Region				
			India	Europe	North America	Others	Total
Gender	Male	Count	154	98	20	6	278
		% within gender	55.4%	35.3%	7.2%	2.2%	100.0%
		% within region	76.2%	71.5%	80.0%	60.0%	74.3%
	Female	Count	48	39	5	4	96
		% within gender	50.0%	40.6%	5.2%	4.2%	100.0%
		% within region	23.8%	28.5%	20.0%	40.0%	25.7%
Total		Count	202	137	25	10	374
		% within gender	54.0%	36.6%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.2 Age group-region cross tab analysis

			Region				
			India	Europe	North America	Others	Total
Age group	Less than 18 years	Count	2	0	0	0	2
		% within age group	100.0%	0.0%	0.0%	0.0%	100.0%
		% within region	1.0%	0.0%	0.0%	0.0%	0.5%
	18–30 years	Count	146	110	18	7	281
		% within age group	52.0%	39.1%	6.4%	2.5%	100.0%
		% within region	72.3%	80.3%	72.0%	70.0%	75.1%
	31–40 years	Count	38	16	3	1	58
		% within age group	65.5%	27.6%	5.2%	1.7%	100.0%
		% within region	18.8%	11.7%	12.0%	10.0%	15.5%
	41–50 years	Count	10	5	1	1	17
		% within age group	58.8%	29.4%	5.9%	5.9%	100.0%
		% within region	5.0%	3.6%	4.0%	10.0%	4.5%
	51–60 years	Count	3	4	1	1	9
		% within age group	33.3%	44.4%	11.1%	11.1%	100.0%
		% within region	1.5%	2.9%	4.0%	10.0%	2.4%
	61 years and above	Count	3	2	2	0	7
		% within age group	42.9%	28.6%	28.6%	0.0%	100.0%
		% within region	1.5%	1.5%	8.0%	0.0%	1.9%
Total		Count	202	137	25	10	374
		% within age group	54.0%	36.6%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

of age group (75.7%). This is followed by the age group 31–40 years (15.5%).The demands and requirements of these age group are valid for the future market requirements as it denotes their aspirations of future consumers for the infotainment market. From Table 6.4, it can be seen that (32.4%) of the respondents don't have a car. This is followed by people owning midsize cars (29.9%) and compact cars (16.6%). Table 6.3 shows that about (47.9%) of the respondents are working in a private organization followed by students (28.9%).

6.4 Results and Discussion

In this chapter analysis on the survey data will be discussed (Table 6.4).

6.4.1 Statistical Analysis

6.4.1.1 Reliability Analysis

Reliability of the scale was carried out using reliability analysis. Cronbach alpha values that are greater than 0.60 were seen to be accepted for this research. The reliability analysis was carried out for questionnaires that used Likert-scale for ranking. In the Likert scale 1 denotes for "Extremely Important," 2 stands for "Important," 3 denotes "Neutral," 4 denotes "Less Important," 5 denotes "Not at all Important." All the values are acceptable as shown in Table 6.5.

6.4.1.2 Analysis of Responses to Questionnaire

It can be seen from the Table 6.6 that overall personalized music and video contents such as private music collection or custom music and video tracks are preferred as the most important sources for entertainment in a car. This is followed by radio listening which is the second-best alternative to people. Within Europe, radio is the most preferred source of entertainment whereas, in India personalized contents are preferred more. Frequency of responses from Europe are high for radio compared to Indian respondents. Females (46.3%) prefer radio compared to males (41.5%).

Table 6.8 shows that music and videos can be played using various devices and shows the preferred devices through which consumers like to enjoy the music or video in a car. As seen in Table 6.7 Indians prefer to play contents from USB Sticks (21.9%) over Europeans (13.8%). However mobile phone integrations is the most preferred device to play contents on the infotainment in a car. This proves the high penetration of smartphones into consumers and a main device for integration in infotainment systems (Table 6.8).

Table 6.3 Employment status-region cross-tab analysis

			Region				
			India	Europe	North America	Others	Total
Car type	Don't have a car	Count	59	58	2	2	121
		% within car type	48.8%	47.9%	1.7%	1.7%	100.0%
		% within region	29.2%	42.3%	8.0%	20.0%	32.4%
	Compact car	Count	36	21	3	2	62
		% within car type	58.1%	33.9%	4.8%	3.2%	100.0%
		% within region	17.8%	15.3%	12.0%	20.0%	16.6%
	Midsize car	Count	61	37	10	4	112
		% within car type	54.5%	33.0%	8.9%	3.6%	100.0%
		% within region	30.2%	27.0%	40.0%	40.0%	29.9%
	Large car	Count	10	6	3	0	19
		% within car type	52.6%	31.6%	15.8%	0.0%	100.0%
		% within region	5.0%	4.4%	12.0%	0.0%	5.1%
	Executive car	Count	5	2	0	1	8
		% within car type	62.5%	25.0%	0.0%	12.5%	100.0%
		% within region	2.5%	1.5%	0.0%	10.0%	2.1%
	Luxury car	Count	5	2	2	0	9
		% within car type	55.6%	22.2%	22.2%	0.0%	100.0%
		% within region	2.5%	1.5%	8.0%	0.0%	2.4%
	Sports car	Count	1	2	0	0	3
		% within car type	33.3%	66.7%	0.0%	0.0%	100.0%
		% within region	0.5%	1.5%	0.0%	0.0%	0.8%
	MUV	Count	1	0	1	1	3
		% within car type	33.3%	0.0%	33.3%	33.3%	100.0%
		% within region	0.5%	0.0%	4.0%	10.0%	0.8%
	SUV	Count	12	6	3	0	21
		% within car type	57.1%	28.6%	14.3%	0.0%	100.0%
		% within region	5.9%	4.4%	12.0%	0.0%	5.6%
	Mini car	Count	12	3	1	0	16
		% within car type	75.0%	18.8%	6.3%	0.0%	100.0%
		% within region	5.9%	2.2%	4.0%	0.0%	4.3%
Total		Count	202	137	25	10	374
		% within car type	54.0%	36.6%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.4 Car type-region cross-tab analysis

			Region				Total
			India	Europe	North America	Others	
Employment status	Self-employed	Count	24	3	1	1	29
		% within employment status	82.8%	10.3%	3.4%	3.4%	100.0%
		% within region	11.9%	2.2%	4.0%	10.0%	7.8%
	Government employee	Count	20	8	0	0	28
		% within employment status	71.4%	28.6%	0.0%	0.0%	100.0%
		% within region	9.9%	5.8%	0.0%	0.0%	7.5%
	Working in private organizations	Count	118	50	8	3	179
		% within employment status	65.9%	27.9%	4.5%	1.7%	100.0%
		% within region	58.4%	36.5%	32.0%	30.0%	47.9%
	Part time	Count	2	7	1	0	10
		% within employment status	20.0%	70.0%	10.0%	0.0%	100.0%
		% within region	1.0%	5.1%	4.0%	0.0%	2.7%
	Student	Count	24	67	12	5	108
		% within employment status	22.2%	62.0%	11.1%	4.6%	100.0%
		% within region	11.9%	48.9%	48.0%	50.0%	28.9%
	Currently not employed	Count	11	2	1	1	15
		% within employment status	73.3%	13.3%	6.7%	6.7%	100.0%
		% within region	5.4%	1.5%	4.0%	10.0%	4.0%
	Retired	Count	3	0	2	0	5
		% within employment status	60.0%	0.0%	40.0%	0.0%	100.0%
		% within region	1.5%	0.0%	8.0%	0.0%	1.3%
Total		Count	202	137	25	10	374
		% within employment status	54.0%	36.6%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.5 Summary of reliability analysis

	Mean	Std. deviation	Number of items	Cronbach's alpha if item deleted
How important are the infotainment system features, when you decide to buy a new car?	2.05914	0.91	372.000	0.666
Rank the features according to their importance for you when choosing car sharing or rental service? [Radio system]	2.16129	1.05	372.000	0.675
Rank the features according to their importance for you when choosing car sharing or rental service? [Navigation]	1.55914	0.83	372.000	0.704
Rank the features according to their importance for you when choosing car sharing or rental service? [Internet connectivity in car]	2.225806	1.16	372.000	0.609
Rank the features according to their importance for you when choosing car sharing or rental service? [Common entertainment for all passengers]	2.655914	1.15	372.000	0.625
Rank the features according to their importance for you when choosing car sharing or rental service? [Separate entertainment for each passenger]	3.389785	1.20	372.000	0.685

Table 6.6 Source of entertainment-region (Q1) cross-tab analysis

			Region				Total
			India	Europe	North America	Others	
Sources of entertainment	Radio	Count	114	111	15	8	248
		% within Q1	46.0%	44.8%	6.0%	3.2%	
		% within region	35.6%	53.4%	37.5%	57.1%	
	Personalized music and video contents	Count	159	81	19	4	263
		% within Q1	60.5%	30.8%	7.2%	1.5%	
		% within region	49.7%	38.9%	47.5%	28.6%	
	Television	Count	9	3	2	1	15
		%within Q1	60.0%	20.0%	13.3%	6.7%	
		% within region	2.8%	1.4%	5.0%	7.1%	
	Web browsing	Count	22	9	3	1	35
		% within Q1	62.9%	25.7%	8.6%	2.9%	
		% within region	6.9%	4.3%	7.5%	7.1%	
	Newspaper and magazines	Count	16	4	1	0	21
		% within Q1	76.2%	19.0%	4.8%	0.0%	
		% within region	5.0%	1.9%	2.5%	0.0%	
Total		Count	320	208	40	14	582

Percentages and totals are based on responses

Table 6.7 Summary of cross-tab analysis (Q2), devices used for entertainment-region

			Region				Total
			India	Europe	North America	Others	
Devices used for entertainment in car	Using internet profiles on infotainment system	Count	101	72	10	6	189
		% within Q2	53.4%	38.1%	5.3%	3.2%	
		% within region	22.3%	23.1%	19.6%	26.1%	
	Connect mobile phone to infotainment	Count	120	100	20	7	247
		% within Q2	48.6%	40.5%	8.1%	2.8%	
		% within region	26.5%	32.1%	39.2%	30.4%	
	Connect virtual reality gears (oculus) to infotainment system	Count	37	20	4	0	61
		% within Q2	60.7%	32.8%	6.6%	0.0%	
		% within region	8.2%	6.4%	7.8%	0.0%	
	CD/DVD	Count	15	20	2	1	38
		% within Q2	39.5%	52.6%	5.3%	2.6%	
		% within region	3.3%	6.4%	3.9%	4.3%	
	USB stick or memory card	Count	99	43	3	4	149
		% within Q2	66.4%	28.9%	2.0%	2.7%	
		% within region	21.9%	13.8%	5.9%	17.4%	
	Broadcast radio	Count	52	47	7	3	109
		% within Q2	47.7%	43.1%	6.4%	2.8%	
		% within region	11.5%	15.1%	13.7%	13.0%	
	Broadcast TV	Count	19	5	4	1	29
		% within Q2	65.5%	17.2%	13.8%	3.4%	
		% within region	4.2%	1.6%	7.8%	4.3%	
	Laptop	Count	10	5	1	1	17
		% within Q2	58.8%	29.4%	5.9%	5.9%	
		% within region	2.2%	1.6%	2.0%	4.3%	
Total		Count	453	312	51	23	839

Percentages and totals are based on responses

The HMI part of the AIS consists of the way consumers like to control the AIS and the display features that the system provides. This is important to understand how consumer expect to enjoy videos in a car. A respondent summary for preferred way of controlling the AIS is shown in Table 6.9. Indians have the maximum preference for voice assistance (50%) compared to Europeans (36.5%). The second-most highly opted for feature is the touch screen control. Controlling with buttons and knobs are still preferred by Europeans (16.1%) compared to Indians (5%).

Table 6.8 Summary of cross tab analysis (Q3), functionalities expected in infotainment-region

			Region				
			India	Europe	North America	Others	Total
Functions expected in car	Music	Count	158	125	20	10	313
		% within Q3	50.5%	39.9%	6.4%	3.2%	
		% within region	31.1%	35.6%	32.8%	41.7%	
	Videos	Count	90	50	13	4	157
		% within Q3	57.3%	31.8%	8.3%	2.5%	
		% within region	17.7%	14.2%	21.3%	16.7%	
	Business utilities	Count	63	57	7	0	127
		% within Q3	49.6%	44.9%	5.5%	0.0%	
		% within region	12.4%	16.2%	11.5%	0.0%	
	Shopping	Count	24	15	3	1	43
		% within Q3	55.8%	34.9%	7.0%	2.3%	
		% within region	4.7%	4.3%	4.9%	4.2%	
	Games	Count	40	11	4	2	57
		% within Q3	70.2%	19.3%	7.0%	3.5%	
		% within region	7.9%	3.1%	6.6%	8.3%	
	Web browser	Count	73	56	9	4	142
		% within Q3	51.4%	39.4%	6.3%	2.8%	
		% within region	14.4%	16.0%	14.8%	16.7%	
	Social - network-ing platforms	Count	60	37	5	3	105
		% within Q3	57.1%	35.2%	4.8%	2.9%	
		% within region	11.8%	10.5%	8.2%	12.5%	
Total		Count	508	351	61	24	944

Percentages and totals are based on responses

As shown in Table 6.10 summary of preference for expectations in the display system of the infotainment. Europeans are more likely to expect flat display screens (34.8%), whereas the Indians are more likely to opt for curved display screens (28.6%). In Europe and America, the most preferred display is the flat screen. Heads-up displays are preferred more in North America (31.6%) followed by Europe (19.1%).

Respondents were asked about the preference on the type of infotainment system they would like to have. The frequency of the responses is shown in Table 6.11. India (60.4%) and North America (68%) prefer a single common system for the whole car. It is the opposite case in Europe where the respondents have mentioned to have a separate entertainment system for each passenger of the car (54%).Table 6.12 shows the importance of infotainment systems in making decisions while buying a car. Overall infotainment plays a significant role in making decisions for car purchase. It is also seen that for Indian respondents AIS features are marked more frequent for “Extremely Important” compared to Europe.

Table 6.9 Summary of crosstab analysis (Q4), preference for controlling the infotainment system-region

			Region				Total
			India	Europe	North America	Others	
How do you prefer to control the infotainment system of your car?	Touch screen	Count	62	43	6	5	116
		% within Q4	53.4%	37.1%	5.2%	4.3%	100.0%
		% within region	30.7%	31.4%	24.0%	50.0%	31.0%
	Buttons, knobs and switches	Count	10	22	4	0	36
		% within Q4	27.8%	61.1%	11.1%	0.0%	100.0%
		% within region	5.0%	16.1%	16.0%	0.0%	9.6%
	Voice assistance	Count	101	50	12	4	167
		% within Q4	60.5%	29.9%	7.2%	2.4%	100.0%
		% within region	50.0%	36.5%	48.0%	40.0%	44.7%
	Human gestures	Count	18	19	3	0	40
		% within Q4	45.0%	47.5%	7.5%	0.0%	100.0%
		% within region	8.9%	13.9%	12.0%	0.0%	10.7%
	Remote control	Count	11	3	0	1	15
		% within Q4	73.3%	20.0%	0.0%	6.7%	100.0%
		% within region	5.4%	2.2%	0.0%	10.0%	4.0%
Total		Count	202	137	25	10	374
		% within Q4	54.0%	36.6%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

Respondents were asked for reasons to listen to radio while driving car. The results are shown in Table 6.13. In all the regions the most frequent response was “No need to choose song each time while driving car.” The second-most frequent response for India is for live traffic updates and weather while in Europe the second-most frequent response is for the news and talk shows that are played on the radio.

Features that are expected by the consumers each have different business car underlying them. From Table 6.14, respondents from India have opted for “Display name of the program along with song title and artist name” as the first option (26.4%). The same goes for Europe with 29.6% opting for that feature. Europeans (27.3%) prefer to “select radio stations by name” compared to the Indians (23.2%). Indians (18.5%) also most likely prefer to the feature “Ability to record, pause and play the program” compared to Europeans (8.8%).

From Table 6.15, respondents have indicated clearly that they listen radio both within cities and in the motorways. This implies that offering solutions for radio reception is of importance where radio coverage is weak. Therefore, new innovations such as IP blending and seamless reception techniques stand a great chance for user adoption.

Table 6.10 Summary of crosstab analysis (Q5), preference for display feature in the Infotainment System-Region

			Region				
			India	Europe	North America	Others	Total
Display technologies preferred in car	Flat display screens	Count	73	71	12	6	162
		% within Q5	45.1%	43.8%	7.4%	3.7%	
		% within region	25.4%	34.8%	31.6%	54.5%	
	Curved display screens that fit nice on your dashboard	Count	82	45	9	2	138
		% within Q5	59.4%	32.6%	6.5%	1.4%	
		% within region	28.6%	22.1%	23.7%	18.2%	
	3D display screen	Count	60	17	3	0	80
		% within $q5	75.0%	21.3%	3.8%	0.0%	
		% within region	20.9%	8.3%	7.9%	0.0%	
	Heads up display (wind shield display)	Count	43	39	12	0	94
		% within $q5	45.7%	41.5%	12.8%	0.0%	
		% within region	15.0%	19.1%	31.6%	0.0%	
	Augmented reality	Count	29	31	2	3	65
		% within $q5	44.6%	47.7%	3.1%	4.6%	
		% within region	10.1%	15.2%	5.3%	27.3%	
	None of the above	Count	0	1	0	0	1
		% within $q5	0.0%	100.0%	0.0%	0.0%	
		% within region	0.0%	0.5%	0.0%	0.0%	
Total		Count	287	204	38	11	540

Percentages and totals are based on responses

Table 6.11 Summary of Responses for crosstab analysis (Q6), preferred type of infotainment system-region

			Region				
			India	Europe	North America	Others	Total
How do you like to have your entertainment system in car?	Individual entertainment system	Count	80	74	8	5	167
		% within Q6	47.9%	44.3%	4.8%	3.0%	100.0%
		% within region	39.6%	54.0%	32.0%	50.0%	44.7%
	Common entertainment system	Count	122	63	17	5	207
		% within Q6	58.9%	30.4%	8.2%	2.4%	100.0%
		% within region	60.4%	46.0%	68.0%	50.0%	55.3%
Total		Count	202	137	25	10	374
		% within Q6	54.0%	36.6%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.12 Summary of cross tab analysis (Q7), importance of AIS features when making car buying decisions-region

			Region				Total
			India	Europe	North America	Others	
How important are the infotainment system features, when you decide to buy a new car?	Extremely important	Count	78	14	8	0	100
		% within Q7	78.0%	14.0%	8.0%	0.0%	100.0%
		% within region	38.6%	10.4%	32.0%	0.0%	26.9%
	Important	Count	95	71	14	6	186
		% within Q7	51.1%	38.2%	7.5%	3.2%	100.0%
		% within region	47.0%	52.6%	56.0%	60.0%	50.0%
	Neutral	Count	20	33	2	3	58
		% within Q7	34.5%	56.9%	3.4%	5.2%	100.0%
		% within region	9.9%	24.4%	8.0%	30.0%	15.6%
	Less important	Count	7	11	1	1	20
		% within Q7	35.0%	55.0%	5.0%	5.0%	100.0%
		% within region	3.5%	8.1%	4.0%	10.0%	5.4%
	Not at all important	Count	2	6	0	0	8
		% within Q7	25.0%	75.0%	0.0%	0.0%	100.0%
		% within region	1.0%	4.4%	0.0%	0.0%	2.2%
Total		Count	202	135	25	10	372
		% within Q7	54.3%	36.3%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.13 Summary of cross tab analysis (Q8), reasons for listening to radio in car-region

			Region				Total
			India	Europe	North America	Others	
Why do you listen to radio when in car?	No need to choose songs each time while driving	Count	131	103	17	7	258
		% within Q8	50.8%	39.9%	6.6%	2.7%	
		% within region	30.8%	35.3%	33.3%	30.4%	
	News program and local events update	Count	106	87	12	6	211
		% within Q8	50.2%	41.2%	5.7%	2.8%	
		% within region	24.9%	29.8%	23.5%	26.1%	
	The talk shows that are hosted on radio program	Count	53	30	7	6	96
		% within Q8	55.2%	31.3%	7.3%	6.3%	
		% within region	12.4%	10.3%	13.7%	26.1%	
	For live traffic and weather updates	Count	117	69	13	4	203
		% within Q8	57.6%	34.0%	6.4%	2.0%	
		% within region	27.5%	23.6%	25.5%	17.4%	
	Commercials	Count	19	3	2	0	24
		% within Q8	79.2%	12.5%	8.3%	0.0%	
		% within region	4.5%	1.0%	3.9%	0.0%	
Total		Count	426	292	51	23	792

Percentages and totals are based on responses

Table 6.14 Summary of cross tab analysis (Q9), features expected for broad cast radio listening-region

			Region				Total
			India	Europe	North America	Others	
What are the important radio features you would like to have in your car?	Select radio stations by name	Count	115	96	16	6	233
		% within Q9	49.4%	41.2%	6.9%	2.6%	
		% within region	23.2%	27.3%	27.1%	26.1%	
	Display name of the program along with song title and artist name	Count	131	103	17	7	258
		% within Q9	50.8%	39.9%	6.6%	2.7%	
		% within region	26.4%	29.3%	28.8%	30.4%	
	Automatic traffic updates when driving your car	Count	127	98	17	6	248
		% within Q9	51.2%	39.5%	6.9%	2.4%	
		% within region	25.6%	27.8%	28.8%	26.1%	
	Receive text or images form the radio station about news report	Count	31	24	3	2	60
		% within Q9	51.7%	40.0%	5.0%	3.3%	
		% within region	6.3%	6.8%	5.1%	8.7%	
	Ability to record, pause and play the program	Count	92	31	6	2	131
		% within Q9	70.2%	23.7%	4.6%	1.5%	
		% within region	18.5%	8.8%	10.2%	8.7%	
Total		Count	496	352	59	23	930

Percentages and totals are based on responses

Table 6.15 Summary of crosstab analysis (Q10), to where people listen to radio in car

			Region				Total
			India	Europe	North America	Others	
Where do you prefer to listen to broadcast radio in car?	Within cities	Count	28	17	3	3	51
		% within Q10	54.9%	33.3%	5.9%	5.9%	100.0%
		% within region	13.9%	12.4%	12.0%	30.0%	13.6%
	Motorways	Count	24	17	2	1	44
		% within Q10	54.5%	38.6%	4.5%	2.3%	100.0%
		% within region	11.9%	12.4%	8.0%	10.0%	11.8%
	Everywhere	Count	141	99	17	6	263
		% within Q10	53.6%	37.6%	6.5%	2.3%	100.0%
		% within region	69.8%	72.3%	68.0%	60.0%	70.3%
	Will not listen radio	Count	9	4	3	0	16
		% within Q10	56.3%	25.0%	18.8%	0.0%	100.0%
		% within region	4.5%	2.9%	12.0%	0.0%	4.3%
Total		Count	202	137	25	10	374
		% within Q10	54.0%	36.6%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6.16 Crosstab analysis for need for radio system if car internet is available

			Region				Total
			India	Europe	North America	Others	
If you have internet in your car, would you still need broadcast radio?	Yes	Count	148	97	17	6	268
		% within Q11	55.2%	36.2%	6.3%	2.2%	100.0%
		% within region	73.3%	70.8%	68.0%	60.0%	71.7%
	No	Count	54	40	8	4	106
		% within Q11	50.9%	37.7%	7.5%	3.8%	100.0%
		% within region	26.7%	29.2%	32.0%	40.0%	28.3%
Total		Count	202	137	25	10	374
		% within Q11	54.0%	36.6%	6.7%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

Respondents were asked the question "If you have Internet in your car, would you still need broadcast radio?". Table 6.16 shows the responses which clearly indicate that people still expect broadcast radio reception in their car.

It can be seen from Table 6.17 that single person future mobility plans clearly indicate that Indian respondents do not prefer public transport for all distances except for a 501–1000 km distance (35.6%). First option being own car (47.5%) and car sharing (24.8%) is a second-best viable option for distances <50 km. However, in the case of Europe public transport (42.2%) is mostly preferred for a distance <50 km, followed by own car (37%). For distances of 51–100 km own car is the most preferred by Indians (47.5%), Europeans (44.4%) and North Americans (52%). Also for 51–100 km distances Europeans are most likely to use ride-sharing service (17.8%) compared to Indians (12.4%). Also, car sharing is preferred as a second alternative to own car and the car sharing is preferred more likely by Indian respondents than European respondents. Clearly for distance >1000 km Airplane is the most preferred mode of transport. Indians are most likely interested in using car as mode of transport except for a distance of 501–1000 km.

Respondents were asked "*When would they use car sharing services?*" From Table 6.18 Indian respondents chose the maximum for daily commutation to work followed by when there are no public transport facilities. European respondents have chosen the maximum of "Never" followed by no public transport facility. Same applies to North America. Overall no proper public transport drives the car sharing and followed by most people don't want to use otherwise.

Table 6.19 shows the summary of responses to "*How do you prefer to have your personalized entertainment experience when using a car sharing or rental service*?". To which clearly all the respondents want to achieve through mobile phone followed by not to have any personalized infotainment experience every time they use car-sharing service. The least frequent response for India, Europe and North America was to have personalized experience using Internet.

Table 6.17 Summary of responses for Q12, single person future mobility based on distance

Distance to be covered (km)	Mode of transport	India	Europe	North America	Others	Total
<50	Own car (%)	47.5	37.0	56.0	33.3	43.9
	Car sharing (%)	24.8	17.0	12.0	16.7	20.9
	Car rental (%)	4.0	1.5	0.0	0.0	2.7
	Ride sharing (carpooling) (%)	8.4	3.0	4.0	0.0	5.9
	Public transport (%)	13.9	42.2	28.0	33.3	25.7
	Aero plane (%)	1.5	0.7	0.0	0.0	1.1
51–100	Own car (%)	47.5	44.4	52.0	41.7	46.5
	Car sharing (%)	21.8	14.1	24.0	16.7	19.0
	Car rental (%)	9.4	9.6	0.0	8.3	8.8
	Ride sharing (carpooling) (%)	12.4	17.8	16.0	0.0	14.2
	Public transport (%)	8.9	14.8	8.0	16.7	11.2
	Aero plane (%)	0.0	0.7	0.0	0.0	0.3
101–500	Own car (%)	48.0	34.1	52.0	16.7	42.2
	Car sharing (%)	8.4	5.9	12.0	0.0	7.5
	Car rental (%)	9.4	9.6	0.0	8.3	8.8
	Ride sharing (carpooling) (%)	12.4	17.8	16.0	0.0	14.2
	Public transport (%)	8.9	14.8	8.0	16.7	11.2
	Aero plane (%)	0.0	0.7	0.0	0.0	0.3
501–1000	Own car (%)	29.2	17.0	32.0	8.3	24.3
	Car sharing (%)	0.0	0.0	0.0	166.7	5.3
	Car rental (%)	10.4	9.6	28.0	0.0	11.0
	Ride sharing (carpooling) (%)	4.0	5.2	4.0	0.0	4.3
	Public transport (%)	35.6	32.6	4.0	25.0	32.1
	Aero plane (%)	13.4	34.1	28.0	50.0	23.0
>1000	Own car (%)	24.8	11.9	16.0	8.3	19.0
	Car sharing (%)	3.5	0.7	4.0	0.0	2.4
	Car rental (%)	8.4	4.4	12.0	0.0	7.0
	Ride sharing (carpooling) (%)	1.5	1.5	0.0	0.0	1.3
	Public transport (%)	6.4	5.9	8.0	8.3	6.4
	Aero plane (%)	55.4	77.0	60.0	66.7	63.9

Percentages shown are calculated within region

Respondents were asked "*Rank the features according to their importance for you when choosing car sharing or rental service?*". Table 6.20, shows the summary of responses. Across all the regions respondents have chosen the maximum for navigation system as extremely important. Radio systems are "Extremely important" to North Americans (32%) compared to Indians (28.7%) and Europeans (28.1%).

Table 6.18 Summary of crosstab analysis for Q13, car sharing use cases-region

			Region				
			India	Europe	North America	Others	Total
When do you use car sharing service?	Never	Count	45	55	9	4	113
		% within Q13	39.8%	48.7%	8.0%	3.5%	
		% within region	15.6%	29.4%	18.0%	33.3%	
	Daily travel to work	Count	66	9	6	1	82
		% within Q13	80.5%	11.0%	7.3%	1.2%	
		% within region	22.9%	4.8%	12.0%	8.3%	
	Business trip to new cities	Count	24	13	6	0	43
		% within Q13	55.8%	30.2%	14.0%	0.0%	
		% within region	8.3%	7.0%	12.0%	0.0%	
	Family vacation	Count	38	17	7	3	65
		% within Q13	58.5%	26.2%	10.8%	4.6%	
		% within region	13.2%	9.1%	14.0%	25.0%	
	Single person vacation	Count	26	26	6	1	59
		% within Q13	44.1%	44.1%	10.2%	1.7%	
		% within region	9.0%	13.9%	12.0%	8.3%	
	No public transport option	Count	65	48	8	3	124
		% within Q13	52.4%	38.7%	6.5%	2.4%	
		% within region	22.6%	25.7%	16.0%	25.0%	
	Socialize with people	Count	24	19	8	0	51
		% within Q13	47.1%	37.3%	15.7%	0.0%	
		% within region	8.3%	10.2%	16.0%	0.0%	
Total		Count	288	187	50	12	537

Percentages and totals are based on responses

Internet connectivity in the car is also extremely important for Indians (40.1%) compared to Europeans (19.3%). Common entertainment systems are "Extremely Important" for Indians (24.8%) compared to Europeans (7.4%) and North Americans (4%). Separate individual entertainment systems are "Important" to Indians (21.3%) compared to Europeans (9.6%) and North Americans (4%). Overall it can be seen that for Indians (22.3%) and Europeans (24.4%) individual entertainment systems are not expected in car-sharing services.

Respondents were asked "*If you were to ride in a completely self-driving vehicle, what would you do in your newly found free time in the car?*". From Table 6.21, Indian respondents have chosen "Enjoy the scenery" (24.2%) followed by "being entertained" (19.3%) was chosen. However, the European respondents have also chosen "Enjoy the scenery" (19.2%) and "Being productive" (19.2%) with business utilities more compared to Indian respondents (16.0%).

Table 6.19 Summary of cross tab analysis for Q14, personalization of infotainment system in car sharing services

			Region				Total
			India	Europe	North America	Others	
How do you prefer to have your personalized entertainment experience when using a car sharing or rental service?	Using internet profile	Count	31	24	6	4	65
		% within Q14	47.7%	36.9%	9.2%	6.2%	100.0%
		% within region	15.3%	18.0%	24.0%	40.0%	17.6%
	Using mobile phone	Count	108	70	10	3	191
		% within Q14	56.5%	36.6%	5.2%	1.6%	100.0%
		% within region	53.5%	52.6%	40.0%	30.0%	51.6%
	No personalization needed	Count	63	39	9	3	114
		% within Q14	55.3%	34.2%	7.9%	2.6%	100.0%
		% within region	31.2%	29.3%	36.0%	30.0%	30.8%
Total		Count	202	133	25	10	370
		% within Q14	54.6%	35.9%	6.8%	2.7%	100.0%
		% within region	100.0%	100.0%	100.0%	100.0%	100.0%

6.4.2 *Statistical Significance of the Demographic Effects*

Table 6.22 shows the one-way ANOVA results that are significant with respect to regions. There is statistically significant difference between infotainment features in buying decisions for the car and the region determined. Europeans differ statistically significantly from Indians and North Americans in the infotainment features for buying decisions. Also, statistically significant difference is seen in Table 6.22 for the infotainment features that are expected in car-sharing services. Indians prefer to have Internet connectivity in the car compared to the Europeans. Overall Indians find the infotainment features to be very important in car-sharing services compared to Europeans.

Table 6.23 shows the one-way ANOVA results that are significant with respect to the car type being used by the respondents. There is statistically significant difference between having navigation and common entertainment for all passengers, when using car-sharing services and the car type the respondents own. Respondents who have compact cars are less likely to emphasize on the navigation feature in car-sharing services. Also, compact car owners are less likely to emphasize on a common entertainment system for all passengers.

Table 6.24 shows the one-way ANOVA results that are significant with respect to employment status. There is statistically significant difference between infotainment features in buying decisions for the car and the region. Self-employed and government employees are more likely to be influenced by the infotainment features

Table 6.20 Summary of responses for Q15, features expected from AIS when using car sharing or rental service

		India	Europe	North America	Others	Total
Radio	Extremely important (%)	28.7	28.1	32.0	0.0	27.8
	Important (%)	48.0	37.8	40.0	58.3	44.1
	Neutral (%)	13.9	24.4	16.0	16.7	17.9
	Less important (%)	5.0	5.2	4.0	8.3	5.1
	Not at all important (%)	4.5	5.9	8.0	0.0	5.1
Navigation	Extremely important (%)	56.9	60.0	72.0	50.0	58.8
	Important (%)	34.7	28.1	20.0	33.3	31.3
	Neutral (%)	6.4	7.4	8.0	0.0	6.7
	Less important (%)	1.0	2.2	0.0	0.0	1.3
	Not at all important (%)	1.0	3.7	0.0	0.0	1.9
Internet connectivity	Extremely important (%)	40.1	19.3	36.0	16.7	31.6
	Important (%)	35.6	31.9	28.0	50.0	34.2
	Neutral (%)	16.8	24.4	28.0	8.3	20.1
	Less important (%)	5.0	11.1	8.0	8.3	7.5
	Not at all important (%)	2.5	14.8	0.0	0.0	6.7
Common entertainment	Extremely important (%)	24.8	7.4	4.0	8.3	16.6
	Important (%)	34.2	21.5	44.0	33.3	30.2
	Neutral (%)	27.7	40.0	48.0	16.7	33.2
	Less important (%)	9.4	13.3	4.0	25.0	11.0
	Not at all important (%)	4.0	19.3	0.0	0.0	9.1
Individual entertainment	Extremely important (%)	9.4	3.7	12.0	0.0	7.2
	Important (%)	21.3	9.6	4.0	16.7	15.8
	Neutral (%)	28.7	29.6	48.0	25.0	30.2
	Less important (%)	22.3	24.4	24.0	33.3	23.5
	Not at all important (%)	18.3	34.1	12.0	8.3	23.3

Percentages shown are calculated within region

Table 6.21 Summary of responses Q17, cross tab analysis for region-using the free time created by self-driving cars

			Region				
			India	Europe	North America	Others	Total
If you were to ride in a completely self-driving vehicle, what would you do in your newly found free time in the car?	Sleep	Count	45	52	7	3	107
		% within Q17	42.1%	48.6%	6.5%	2.8%	
		% within region	9.2%	13.0%	11.1%	10.3%	
	Being productive (work/school work)	Count	78	77	10	3	168
		% within Q17	46.4%	45.8%	6.0%	1.8%	
		% within region	16.0%	19.2%	15.9%	10.3%	
	Being social (talk with friend, chatting)	Count	74	63	12	6	155
		% within Q17	47.7%	40.6%	7.7%	3.9%	
		% within region	15.2%	15.7%	19.0%	20.7%	
	Being entertained (music, videos, games)	Count	94	74	14	9	191
		% within Q17	49.2%	38.7%	7.3%	4.7%	
		% within region	19.3%	18.5%	22.2%	31.0%	
	Enjoy the scenery	Count	118	77	10	5	210
		% within Q17	56.2%	36.7%	4.8%	2.4%	
		% within region	24.2%	19.2%	15.9%	17.2%	
	Be cautious and still watch the road	Count	78	58	10	3	149
		% within Q17	52.3%	38.9%	6.7%	2.0%	
		% within region	16.0%	14.5%	15.9%	10.3%	
Total		Count	487	401	63	29	980

Percentages and totals are based on responses

Table 6.22 Results of one-way ANOVA for regions

Question	F	Sig.	India	Europe	North America	Others
How important are the infotainment system features, when you decide to buy a new car?	15.571	0.000	1.81	2.44	1.84	2.5
Rank the features according to their importance for you when choosing car sharing or rental service? [Internet connectivity in car]	16.315	0.000	1.94	2.71	2.08	2.1
Rank the features according to their importance for you when choosing car sharing or rental service? [Common entertainment for all passengers]	18.321	0.000	2.34	3.15	2.52	2.7
Rank the features according to their importance for you when choosing car sharing or rental service? [Separate entertainment for each passenger]	8.776	0.000	3.19	3.74	3.2	3.4

Table 6.23 Results of one-way Anova for car type

Question	Sig	F	Don't have car	Compact car	Midsize car	Large car	Executive car	Luxury car	Sports car	MUV	SUV	Mini car
Rank the features according to their importance for you when choosing car sharing or rental service? [Navigation]	0.018	2.27	1.55	1.94	1.39	1.53	1.38	1.56	1.67	1.33	1.38	1.75
Rank the features according to their importance for you when choosing car sharing or rental service? [Common entertainment for all passengers]	0.044	1.95	2.93	2.47	2.62	2.84	2.38	1.89	2.00	2.67	2.24	2.69

Table 6.24 Results of One-way ANOVA for employment status

Question	Sig.	F	Self employed	Government employee	Working in Private organizations	Part time	Student	Currently not employed	Retired
How important are the infotainment system features, when you decide to buy a new car?	0.000	5.62	1.72	1.54	2.01	1.90	2.31	2.73	1.60
Rank the features according to their importance for you when choosing car sharing or rental service? [Common entertainment for all passengers]	0.001	3.672	2.83	1.86	2.59	2.60	2.93	2.80	2.40
Rank the features according to their importance for you when choosing car sharing or rental service? [Separate entertainment for each passenger]	0.000	4.739	3.31	3.86	3.17	3.20	3.74	3.60	2.00

compared to students and those currently not employed in the infotainment features for buying decisions. Furthermore, there is statistically significant difference in the expectation of the entertainment system such as a single common entertainment system or an individual entertainment system. Government employees are more likely to expect common infotainment features when using a car-sharing service.

6.5 Conclusion

This thesis work examines the consumer expectations from the automotive infotainment system. A comprehensive literature analysis was used to identify the megatrend studies. It was founded that several global megatrends such as changing demographics, shifting in economic power where now economic focus is turned towards BRICS nations were studied. Furthermore, the rapid urbanization, technological advancements and environment-friendly solutions were found to be the main megatrend drivers. Later on, literature concerning the impact of global megatrends on AIS market were studied. It is found that, the OEMs benefit by partnering with the automotive semiconductor industry. Also the benefits of SDR platforms were studied. Clearly there is a strong competition in the infotainment software platforms, where mobile phone giants such as Google and Apple are aggressively competing to gain the market share. Also, there are several open-source platforms that are widely being developed in order to foster open-source innovation.

The literature review was also used to identify the factors that influence the consumer expectations from AIS. Consumer expectations are broadly dependent on cultural, social, demographics, technology adoption and lifestyle factors. Several theories that explains these behaviors were studied. Also, literatures that examined these mentioned factors specific to AIS were reviewed.

One of the main objective of the thesis was to conduct a market survey to determine the features that are expected by the consumers in the AIS. To achieve this a questionnaire was developed, with the explanation for underlying reasons to each question was discussed. The survey responses were analyzed mainly for the European and Indian markets. However, since the questionnaire was distributed in open platforms, responses for North America and other countries were also present. The main findings from the survey are that the influence of infotainment features on buying decision is more in India compared to Europe. The second important finding is that the features that are expected from the infotainment systems on a car-sharing or rental service is different across the regions. Indians are most likely to expect Internet connectivity in car-sharing services and generally see infotainment features to be very important in car-sharing services compared to Europeans.

Consumers still places a lot of importance on the car radio system. Though personalized music and video contents are preferred a lot, radio systems can be still seen as not completely replaceable in the near future. Also, Europeans see a strong requirement for radio systems compared to Indians who prefer personalized music and video contents. The features that are expected for the radio system are the display name of the programs and selecting the radio stations by their name. Also, Indians are most likely to expect the feature for recording the broadcast radio programs. Additionally, it can be seen that radio is listened to widely within cities and also in motorways, so in places where radio signals are weak, the features such as IP-blending technology for seamless reception have a good future.

The other findings are that voice assistance is the most preferred way of controlling the AIS and flat display screen are preferred. It was shown that the car still remains as the preferred mode of transport for future mobility. It was found that in future with completely self-driven cars people expect features for entertainment and productivity features in the car to make use of free time.

As future research it is proposed to collect more data from people of different age groups and more female participants. Also, the analysis could become more significant if large samples are collected from North America to get statistically significant results if the survey is focused on this region and China.

Appendix: Survey Questionnaire

In-Car Entertainment

In this section, consumer preference for infotainment features that they would like to have in their future car are studied.

1. What is your primary source of entertainment in car?* (multiple responses possible)
   (a) Radio
   (b) Personalized music and video contents
   (c) Television
   (d) Web browsing
   (e) Newspaper and magazines
   (f) Others
2. How do you like to play music or video in car?* (multiple response possible)
   (a) Using Internet profiles on infotainment system
   (b) Connect mobile phone to infotainment unit
   (c) Connect virtual reality gears (Oculus) to infotainment system
   (d) CD/DVD
   (e) USB stick or memory card
   (f) Broadcast radio
   (g) Broadcast TV
   (h) Laptop

3. What following functions, you would like to have in your new car?* (multiple responses possible)
   (a) Music
   (b) Videos
   (c) Business utilities
   (d) Shopping
   (e) Gaming
   (f) Web browser
   (g) Social networking platforms
4. How do you prefer to control the infotainment system of your car?* (only one response possible)
   (a) Touch screen control
   (b) With buttons, knobs and switches
   (c) Voice assistance
   (d) With human gestures
   (e) Remote control
5. What display feature you prefer to have in your car for experiencing videos? * (multiple responses possible)
   (a) Flat display screen
   (b) Curved display screens that fit nicely on your dashboard
   (c) 3D display screen
   (d) Heads-up display (wind shield display)
   (e) Augmented reality
   (f) Others
6. How do you like to have your entertainment system in car? * (only one response possible)
   (a) Individual entertainment system for each passenger
   (b) Single entertainment system for all passengers
7. How important are the infotainment system features, when you decide to buy a new car? * (only one response possible)
   (a) Extremely important
   (b) Important
   (c) Neutral
   (d) Less Important
   (e) Not at all important

Car Radio

In this section, analysis of consumer behavior for listening to radio in the car and radio features they would like to have is studied:

8. Why do you listen to radio when driving? * (multiple responses possible)
   (a) No need to choose songs each time while driving
   (b) News program and local events
   (c) The talk shows that are hosted on radio program
   (d) For live traffic and weather updates
   (e) Commercials
9. What are the important radio features you would like to have in your car? * (multiple responses possible)
   (a) Select radio station by their name and not by the radio station frequency number
   (b) Display name of the program along with song title and artist name
   (c) Automatic traffic updates when driving your car
   (d) Receive text or images form the radio station about news report
   (e) Ability to record, pause and play the program
   (f) Others
10. Where do you prefer to listen to broadcast radio in car? * (only one response possible)
    (a) Within cities
    (b) In motorways (highways)
    (c) Both within cities and motorways
    (d) I do not listen to radio
11. If you have Internet in your car, would you still need broadcast radio? * (only one response possible)
    (a) Yes
    (b) No

Impact of Sharing Economy on Infotainment Systems

In this section consumer preference for future mobility and their entertainment experience in sharing economy is studied.

Sharing economy is an economic model in which individuals are able to borrow or rent assets owned by someone else:

1. Car sharing means renting a car for shorter period of time, usually by hours whenever needed.

2. Car rental means renting a car for longer period of time, usually on a day basis.
3. Ride sharing (carpooling)—the concept of sharing space within a given vehicle along with other people (e.g., blabla car).

12. Please mark your preference for single person, future mobility based on the distance you want to cover? * (only one response possible for each row)

	Own car	Car sharing	Car rental	Ride sharing	Public transport	Airplane
<50 km						
50–100 km						
100–501 km						
501–1000 km						
>1000 km						

13. When do you use car-sharing service? * (multiple responses possible)

    (a) Never
    (b) Daily travel to work
    (c) Business trip to new cities
    (d) Family vacation
    (e) Single-person vacation
    (f) No public transport options
    (g) Socialize with people
    (h) Others

14. How do you prefer to have your personalized entertainment experience when using a car-sharing or rental service? * (only one response possible)

    (a) Using an Internet profile (e.g., Facebook, Google accounts)
    (b) Using mobile phone
    (c) I do not want to have personalized setting in shared or rental car

15. Rank the features according to their importance for you when choosing car sharing or rental service?* (only one response possible for each row)

	Very important	Important	Neutral	Less important	Not at all important
Radio system					
Navigation					
Internet connectivity in the car					
Common entertainment for all passengers					
Separate entertainment for each passenger					

Autonomous Cars

Fully autonomous or completely self-driven cars are cars that will control all safety-critical functions for the entire trip and do not require human intervention at all.

16. What do you like the most about completely self-driving cars? * (multiple response possible)
    (a) Provides extra free time
    (b) No need to learn about driving a car
    (c) Reduces the stress due to driving
    (d) Good solution for physically challenged people
17. If you were to ride in a completely self-driving vehicle, what would you do in your newly found free time in the car? * (multiple response possible)
    (a) Sleep
    (b) Being productive (work/school work)
    (c) Being social (talk with friend, chatting)
    (d) Being entertained (music, videos, games)
    (e) Enjoy the scenery
    (f) Be cautious and still watch the road

Demographic Details

In this section, please provide your demography details in order to perform the study. Since this study is conducted on a whole group and not an individual, your names are not necessary. So, feel free to give your details.

18. Gender * (only one response possible)
    (a) Male
    (b) Female
19. Age group * (only one response possible)
    (a) Less than 18 years
    (b) 18 to 30 years
    (c) 31 to 40 years
    (d) 41 to 50 years
    (e) 51 to 50 years
    (f) 61 years and above
20. Which region do you live? * (only one response possible)
    (a) India
    (b) Europe

(c) North America
(d) South America
(e) China
(f) Others

21. What type of car you drive frequently? * (only one response possible)

(a) I do not have a car
(b) Compact/small cars
(c) Midsize cars
(d) Large cars
(e) Executive cars
(f) Luxury cars
(g) Sport cars
(h) Multipurpose vehicle (MPV)
(i) SUV
(j) Mini cars

22. What is your current employment status? * (only one response possible)

(a) Self-employed
(b) Employed in the government
(c) Employed full time in a private organization
(d) Employed part time
(e) Student
(f) Currently not employed
(g) Retired

* Questions marked star are compulsory to answer

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Chapter 7
Creativity in Design Process Using TRIZ: Application to Smart Kitchen Design

Burcu Taşkın, Nuri Başoğlu, Tuğrul Daim, and Husam Barham

7.1 Introduction

The design of innovative products is an important topic in both the design and management fields. Firms are faced with the challenge of designing innovative products that have high quality and short product life cycle in the same time, while also addressing the needs of end users and create value for them in the context of functionality, economics, ergonomics, aesthetics, among other factors. Researchers developed many creative approaches to design innovative products with these requirements. Such methods start with demand and well-organized problem definition [1–4].

TRIZ is a prominent methodology that includes techniques and toolkits that can be used to logically develop creativity for the process of designing innovative products. TRIZ allows for a fast product design process while using inventive problem-solving techniques that maintain quality and innovation instead of compromising on either of them [5].

This study aims at exploring TRIZ use for innovative product design and to offer better a understanding of the value of TRIZ in the design process and the quality of the design solution for a specific problem. This will be done by conducting an

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experiment, in which two groups of design students will be asked to identify the design requirements of a smart kitchen that answers a specific problem and to propose a product through needs and demands. One group will be asked to use TRIZ, while the other group will use a traditional design approach.

The results of the assignment from both groups will be compared and discussed in terms of the design process and quality of the project solutions, to better understand how TRIZ is different and what value it can add to the design process.

7.2 Literature Review

7.2.1 Creativity in the Design Process and in Problem Solving

Creativity is discussed in many disciplines including the design field. There are many definitions of creativity. A common definition from the Webster's dictionary is "the ability or power to create-to bring into existence, to invest with a new form, to produce through imaginative skill, to make or bring into existence something new" [6]. According to Roger von Oech "creative thinking involves imagining familiar things in a new light, digging below the surface to find previously undetected patterns, and finding connections among unrelated phenomena" [7].

Creativity is interrelated with new product development through alternating the problem solutions. The fundamental factors of personal creativity are related to the person's "intelligence, knowledge, thinking styles, personality, motivation, and environmental context" [8].

Psychologist Sternberg's definition of creativity is illustrated as

$$\mathrm{C} = \mathrm{f}\ (\mathrm{I}, \mathrm{K}, \mathrm{TS}, \mathrm{P}, \mathrm{M}, \mathrm{E}) \tag{7.1}$$

(1) "where C is creativity, I is intelligence, K is knowledge, TS is thinking styles, P is personality, M is motivation, and E is environmental context" [9].

Relative to Sternberg's research, Li [10] developed a creativity model for product innovation. The qualitative expression of their design creativity definition is

$$\mathrm{DC} = \mathrm{f}\ (\mathrm{K}, \mathrm{I}, \mathrm{TS}, \mathrm{DM}, \mathrm{ST}, \mathrm{U}) \tag{7.2}$$

(2) "where, DC is design creativity in product innovation, K is knowledge, I is information, TS is thinking styles, DM is design methods and ST is computer-supporting tools, U is uncontrolled and unchanged factor in a short time, could be uncertainties, such as environment and culture" [10].

Approaches on creativity depend on the field and profession related to the problem to be solved. Moreover, Cross compared scientists' and designers' views on problem solving claims that "scientists use problem-focused strategies for problem solving, whereas designers focus on the solution to a given problem" [11]. Thus, scientists prefer analysis while designers prefer synthesis for problem solving.

Furthermore, Christiaans indicated that "The more time a subject spent in defining and understanding the problem, and consequently using their own frame of reference in forming conceptual structures, the better able he/she was to achieve a creative result" [12]. However, saving time for design process in creativity process is important in competitive markets, where time to market is of critical value. Saving time can be made possible by defining and framing the design problem. According to Dorst and Cross "creativity in the design process can validly be compared to such bursts of development" [13].

Therefore, it can be seen that creativity is important for problem solving related to designing innovative new products. Moreover, linking creativity with well-structured problem definition would allow for fast, while still creative and of quality, product design [2, 4, 13].

7.2.2 *Innovation in New Product Development*

It can be seen from literature that innovation has been the subject of many studies over the years [14–16]. Barnett defined innovations as "any thought, behavior or thing that is new because it is qualitatively different from existing forms and is the basis of cultural change" [17].

Innovations supply "newness" or "differences" that include value providing in products, processes, technologies, methods and business models from new elements or from the same elements that been used/created earlier. Furthermore, innovations are creations that are often built by the occurrence of one or more events with "small/low success probabilities' that may require "high problem resolution." Those creations show "possibility effect of a particular solution or deliverable in the native state of occurrence of the events in the product, process, technology, method or business model" and hence can be called "innovation events" [18].

Researchers emphasize the importance of innovation for problem solving. It was pointed out in the literature that innovation has economic value in terms of design and efficiency that can be reflected in new product development (NPD) process design. Therefore, design-driven NPD provides competitive advantage, evolves technical performance and reduces production costs [19].

Moreover, innovation proposes new products and services including transformed ideas that are precipitated by creativity [20]. Creative design is the core of product innovation, which is a key factor of enterprise innovation [21]. Furthermore, effective innovation process with a structured design method pushes business forward for NPD [22].

In addition, some internal factors such as new technologies, investing on research and development activities, generate competitiveness between firms on innovation and NPD process. Customer and market specifications [23] and the policy of the firm for future business [24] lead to innovation as well as the suppliers' competition requirement that is formed by the technological improvement.

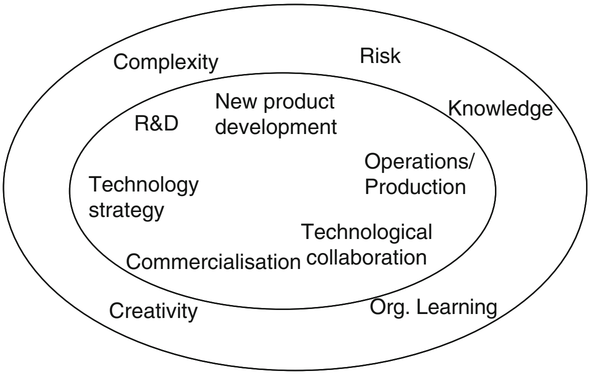

Fig. 7.1 Management of technological innovation: a holistic approach

Innovation does not always connote utilization of the state-of-the-art technology. Conversely, it is less a question of technology and more a way of thinking and finding creative solutions within the firm [25]. Within this scope, Innovation Management Techniques (IMTs) can be considered as a stream of tools, techniques and methodologies that supply a systematic way for adaptation of conditions and meeting market challenges to the firms [26].

Figure 7.1 "proposes a holistic model that includes six specific areas in the management of technology innovation, which is complex and risky: R&D, new product development, commercialization of innovation, operations and production, technological collaboration and technology strategy" [27]. Therefore, the innovation process and innovation management are significant for the dimension of innovation. The innovation process also includes designing with a well-structured problem definition.

Through innovation, firms are able to gain more influence, making innovation management a high priority for firms [28]. Moreover, innovation is a strategically fundamental element for the global economy; it gives firms the ability to expand and reach more stakeholders and high achievement [29]. Innovation also held the promise, that the use of technology can be improved based on market needs and thus a higher opportunity to get more satisfied customers.

By concentrating more on value creation, the firm is trying to adapt itself more quickly and more effectively to the benefit of valuable customers [30].

Innovation management is

- Preconditions' creation to support creativity;
- A process to encourage knowledge application [28].

Designers deal with the NPD in terms of innovation and design method to create competitiveness for the firm. The value creation through the end user among the issues must be considered by the design. Also, new product development process and management, with effective knowledge structure that incorporates the product design process, are essential aspects for the success of new products [31, 32].

Another issue to be considered related to what innovation management techniques (IMTs) to use. In spite of some principles of good applications existing, there is no single ideal model for innovation management [25]. Firms can realize more benefits and effective outcome by integrating two or more IMTs. Such integration should be based on an understanding of what value each IMT can offer, and by having clear definition of aims and the criteria, regarding the survival, growth, new product introduction, competitiveness, and so on. So, a proper mix of IMTs can be used for an optimal outcome [31].

In conclusion, product design process, which consists of "integrated efforts, including generating ideas, developing concepts, modifying details, and evaluating proper solutions" [33], is fundamental for new product development.

7.2.3 TRIZ as a Design Method in New Product Development

The theory of inventive problem solving or TRIZ (TRIZ is an acronym for the original name in Russian language) emerged in the 1960s in the former Soviet Union. It is a systematic approach to define and handle challenging problems. TRIZ is becoming an increasingly popular methodology in product development and design [5, 34–36].

According to Kaplan, the TRIZ methodology claims that 'Inventive problems can be codified, classified and solved methodically, just like other engineering problems' [37, 38]. Moreover, TRIZ offers three premises, the ideal design with no harmful functions is a goal, an inventive solution involves wholly or partially eliminating a contradiction, and the inventive process can be structured [38].

Altshuller, the founder of TRIZ, found out, based on extended analysis of patents that started in 1946 and spans for decades, that systems tend to evolve toward ideality, in an s-curve shape, and the steps to move from one phase to another phase on the s-curve are predictable. Furthermore, Altshuller introduced 40 inventive principles for solving technical contradictions using TRIZ based on this "predictability" [39–41]. The TRIZ concept is based on the hypothesis that creative innovation is based on a set of universal principles of creativity, which offers a different approach than what people understand and anticipate regarding the creativity process. Furthermore, TRIZ includes strategies to address the following innovation challenges: contradictions, ideality, functionality and use of resources [39, 40, 42, 43].

Savransky described TRIZ as a "human-oriented knowledge-based systematic methodology of inventive problem solving" [42]. Similar to this idea, Souchkov [44] defines TRIZ as a three-pillar-based research:

1. Analytical logic
2. Knowledge-based philosophy
3. A systematic way of thinking

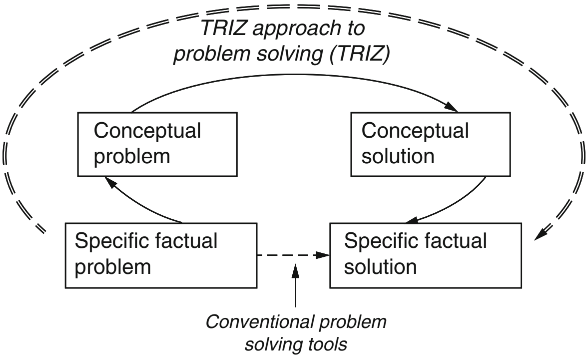

Fig. 7.2 TRIZ systematic approach to problem solving [47]

These three leading conclusions of more than 65-year research, offer creative solutions to problems in industry and sciences. Additionally it offers systematic innovation to accelerate the ways of creative problem solving, which tries to cover all possible ways to be innovative while doing invention-related problem solving [45, 46].

Figure 7.2 shows the TRIZ process.

Figure 7.2 demonstrates how TRIZ offers a quick approach to solve problems: first, a specific problem can be abstracted/conceptualized to a general TRIZ problem, then based on the general TRIZ solution to that problem, a specific innovative solution can be reached in a timely manner [47].

In conclusion, design methods are essential elements for creative design. The designers' creativity can be positively affected by a well-structured design methodology [10]. To develop strategies properly, it is important to demonstrate correctly defined and presented design problems. Moreover, design methods with high-qualified representation and conceptual construction raise the efficiency of the result with half performance of the designers, and this is where TRIZ offers value and can be useful as a methodology that guides a design process that generates innovative products with high quality and fast time-to-market.

7.3 Methodology

7.3.1 Research Method

The research was conducted in three phases as shown in Fig. 7.3. In the first phase, the professionals are involved into the focus group to prepare the assignment for the second phase. The third phase is to discuss, evaluate and compare the design process of the two problem-solving approaches (Table 7.1).

The methodology used to achieve the objective of the descriptive experiment was organized in the following steps:

- The Design Assignment

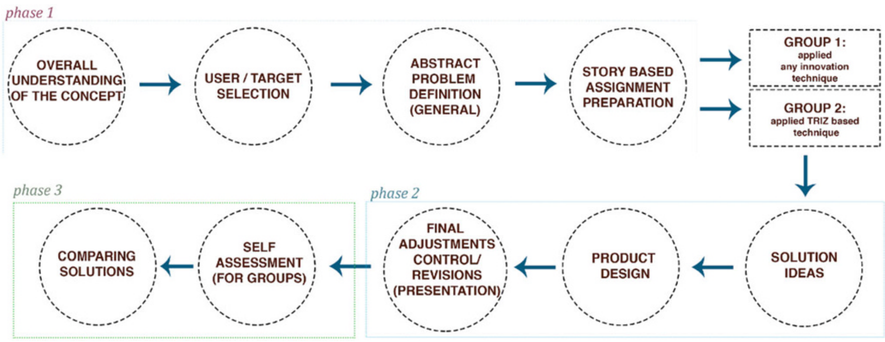

Fig. 7.3 Research flow

Table 7.1 Application phases and group information

Phases	Groups	Participants	Objectives
P1	Focus Group	10 professionals (2 computer engineers, 2 mechanical engineers, 2 city planner 2 architect, 2 designer)	To prepare a detailed assignment with a specific target and design problem
P2	Group A (Chosen by the students who do not know TRIZ)[a]	6 students(2 architects, 2 computer engineers, 2 mechanical engineers)	Free to use any innovation method
	Group B[a]	6 students(2 architects, 2 computer engineers, 2 mechanical engineers)	Applied TRIZ-based innovation method
P3	Professionals Group A, Group B[a]	3 professionals, Group A and B	Self-assessment, grading the assignments

[a]The student groups and professional industrial designers are selected from the Izmir Institute of Technology with an announcement at campus

Preparing a design problem with the focus group for the assignment that will apply to two groups.

The focus group prepared the design assignment considered to be challenging, realistic, feasible in time, appropriate for experimental process and within the sphere of knowledge of the researchers. The assignment was to create a conceptual solution for a smart kitchen to working people in Izmir, Turkey. The problems were defined through the working people and their needs and demands for a smart kitchen. The specifications of problem required the designers concerning the integration of a variety of technology, creativity, engineering, aesthetics and innovation aspects. The information they needed was prepared on information sheets, with one specific topic on each sheet. Designers were free to ask anything to researchers during the design experiment process.

The design problem is limited by the target, space and function.

- The Design Assignment or Problem

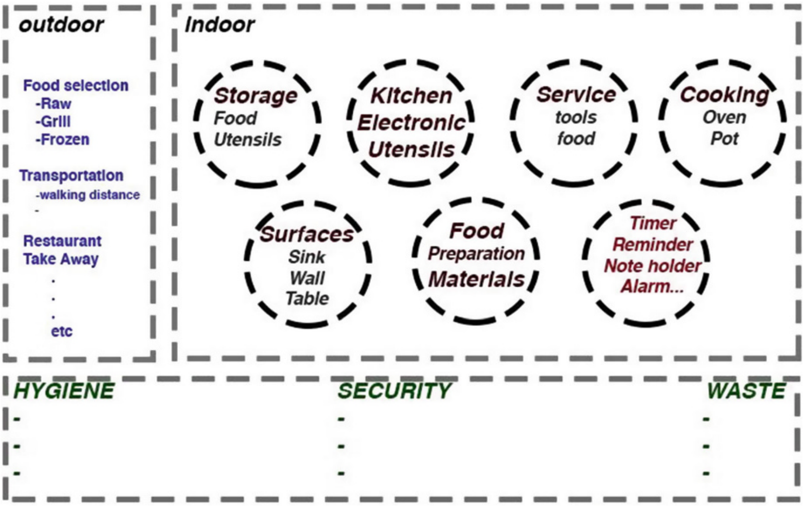

Fig. 7.4 Template for assignment

To produce a smart kitchen for working people that have time limitation for preparing food.

- Division of the Groups

Division of the groups by application of innovation technique such as TRIZ-based technique and any design technique that is used in product innovation. Group A: not limited by any technique for problem solving, Group B: TRIZ-based techniques explained to the group to use for the problem solving. The designers were asked to develop a solution by the help of a sketch or text. The groups are not limited by time and number of the design solution.

- The Experimental Procedure

Before the experiment the groups meet and took their time for knowing each other the experimental procedure and participant rights were explained briefly. The information they needed was prepared on information sheets, with the template (Fig. 7.3) for selected activities and functions for the assignment. Designers were free to ask anything to researchers during the experimental process. Group A directly started the assignment with the template on the given problem. Group B took a lecture on TRIZ-based innovation technique for structuring the problem abstract. The lecture with 25 slights took 40 min to explain TRIZ and samples (Fig. 7.4).

- Data Analysis: Self-Assessment and Professional Grading

To understand the performance of the groups through methods two questionnaires are prepared for self-assessment and grading by professionals. The answers are compared through methods and outcomes of the designs. The structured interview phase is performed after the assignment part.

For reducing complex processes of design activity and simplifying design objects the professional industrial designers grade the outcomes of the assignment regarding their solution, design requirements, design process and feasibility.

Self-assessment is conducted to understand the methods for the problem-solving experience of the participants. The interview applied to get feedback to describe the application of methods in the design process.

7.4 Results and Findings

7.4.1 Phase 1 Results

The focus group defined a problem on innovative design with a specific target. The assignment is detailed as listed below:

- The groups should solve the problem in a short time period.
- The design problem should be chosen in an area that is not common in the existing market or everyday life to make the groups feel free to be innovative and creative.
- The challenges of the assignment should be understood easily.
- The target should be chosen as the groups can imagine easily for empathetic thinking.

Focus group defined the assignment considering the details as

- The focus group chose people from the working class, who are facing everyday life challenges.
- Time is essential for working people.
- The common problem is time.
- Mainly, working people tend to prefer the smart kitchen.
- The food should be healthy because nutrition is a basic need.

The listed issues are guiding the story-based assignment.

7.4.2 Phase 2 Results

Group A took the assignment and start discussions on the assignment by creating mind map, brainstorming on the given problem as given in the steps below:

- Different general ideas to alternate the solutions and the existence of decomposition
- The main ideas to solve the problem, the use of analogy. The development of ideas
- The development of ideas and the initial concept

Table 7.2 Conceptualization of the problem and the solution

The conceptual problems are	The conceptual solutions are
– Control of the expiration date of food	– Date alert that controls the toxins in the food
– Heating the food on time	– Food-heating unit to reduce heating time that the people mostly waste the time

Solution: The combination of the conceptual solutions that offers heating-cooling system, and date alert for rotten food

Table 7.3 Grades of the groups[a]

	Group A	Group B
Reliability of product	3	5
Feasibility of product with Today's technology	2	5
Problem solving	2	5
Design process(productivity)	2	5
Design quality and creativity	2	4
Functional value of solution	4	4

[a]The grades are scored out of 5. For the Group A the technologic kitchen design solution is calculated

- Optimizing the process of ideas and sketching concepts. Evaluation of some ideas
- Describing again the solution, evaluating and iterated for apparent optimization

The major solutions are to improve a service system for ordering food from restaurants, and a technologic kitchen that could cook by itself.

7.4.2.1 Group B Application of the TRIZ Method

Problem definition is rewritten to narrow the scope: smart kitchen design to save time and energy in a healthy way for working people between 20 and 40 years old.

They organized the structure of the method as problem abstraction, conceptual problem and conceptual solution.

The problem abstracts: The template used for abstract the problem as: Time-food, time-preparation, and time-service relations (Table 7.2).

7.4.3 Phase 3 Results

Three professional industrial designers graded the design solutions through reliability, feasibility, technology, problem-solving design process design quality and function with scores between 1 and 5. The average of the each grade is taken (Table 7.3).

Table 7.4 Self-assessment results[a]

Satisfaction on	Group A	Group B
Achievement	5	8
Productivity	5	7
Sufficiency	4	5
Creativity	6	7
Time management	4	8

[a]The grades are scored out of 10

The results show that TRIZ constructed the problem and created a solution systematically. The efficiency was raised and the process time was reduced while the solutions were effective.

The self-assessment results are coded as comparing the advantageous method with the participants that attended to the experiment (Table 7.4). They are asked to grade the each question over 10.

The group B, which used TRIZ, found the results more satisfying, in comparison with the other group in terms of achievement, productivity, sufficiency and time management. Infact, time management is the most significant difference that is observed.

7.5 Discussion

The food culture and daily-life activities are predominant through cultural issues. The cultural domains and life styles are the significant factors through needs and demands. In addition, the kitchen, where the people create private space involves a lot of issues concerning to cultures, income levels, social statuses, life styles, etc. Thus, the study focus on constellation related to these issues to discuss the major problems. The results can be variable for different cultures.

The time limitation for the TRIZ lecture and the heterogeneous background of the students through their knowledge and creativity levels are related to the results.

Group A tried to answer the problems for each function. The template usage is weak and they did not organize their methods properly. They tried different methods until they identified a good idea. They could not improve this idea in the given time. The main answers are discussed as follows:

- The first solution is to improve the existing system, which does not answer the problem correctly.
- The second solution's technology does not exist yet today.

The Group B was successful in applying TRIZ for problem solving in a systematic way. Even though TRIZ was not applied comprehensively; the results show the positive effect on time management and design process.

The self-assessment depends on personal preferences that can be variable. The self-assessment results of this study show that the TRIZ techniques are beneficial to designers for the design process.

One of the problems in the innovation process is related to the lack of knowledge on methodologies. The methodology guides the process to achieve success in the innovation field. This study claims that raising awarenees regarding TRIZ applications on product design will improve the achievement of goals and management of innovation. The time management of Group A was not systematic because of lack of experience regarding any structured methodology. The participants note that the effectiveness of the integrated techniques such as TRIZ in innovative design is considerable because of its systematic approach that decreases time while developing creativity, achievement, sufficiency and productivity.

7.6 Conclusion

Creativity and innovation are fundamental issues in the new product design for both academics and practitioners.

A well-structured problem definition and the design methods are different for each field.

Developing systemic methods based on TRIZ can help designers form systemic creative thinking. However; it is not commonly used by designers. The results show that design methods like TRIZ significantly reduce the time period of the design process and increase the quality of the design. In this paper's experiment, the designers were satisfied with TRIZ application in term of achievement, productivity, sufficiency and time management. TRIZ-based systems on engineering and management are being increasingly developed. In this context, the research supports that TRIZ-based designs create significant time saving and raising the design quality.

Problem's definition is an important step towards finding a solution. The TRIZ technique add value to the design process in terms of reorganizing the problem definition.

In more detailed problem definition, there is considerable use of innovation management tools and techniques for the systematization of the design process.

For further research, studies on the innovation methods in design, which is a complex process, could be varied and applied to different groups and fields.

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Chapter 8
Additive Manufacturing (AM) Technology Assessment for Titanium Hip Implant Fabrication

Ece Üreten, Thomas Willett, Mihaela Vlasea, and Tuğrul Daim

8.1 Introduction

8.1.1 Motivation and Research Objectives

The paradigm shift towards digital manufacturing [1] is seen in additive manufacturing (AM) corporate annual industry growth at 17.4% increase in 2016 to $6.063 billion, with 11% attributed to the biomedical sector [2]. The adoption of AM in healthcare has boomed since 2010 by a 3200% increase in hospitals with AM facilities [2]. Forecasts predict that AM will become common, with a disruptive effect on supply chains [2]. For high-value custom surgical instruments and implants, the metal AM design-to-fabrication lifecycle is performed via costly empirical approaches, hindering widespread technology acceptance [3]; thus, metal AM technologies have not yet reached their full potential in the healthcare industry. With the rapid growth of AM in the field of medical [4], several technologies are becoming popular in producing medical implants. Such technologies need to be distinguished precisely with respect to their capabilities to produce a specific implant. Customization of implants' complex manufacturing approaches is nowadays possible by AM. Therefore, the rising demand for the use of AM technologies for the medical implant production shows its importance for different stakeholders in the healthcare industry and is expected to be continued in the future.

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Selecting the right technology according to the needs of the stakeholders and technology capabilities poses a great challenge to companies to achieve successful outcomes. Wrong choices bring along monetary as well as time losses. As reported in the literature, technology assessment methodologies vary significantly but can provide useful tools to understand market preferences [5]. Therefore, company members gather information on trade shows, conferences, networking events or other research channels to further identify the developing market needs and acquisition of new technologies. Moreover, a connection to university research labs poses great opportunities to learn more about current and future technologies [6].

The fastest emerging metal AM technology for the biomedical field is powder bed fusion which is especially expanding in the medical field for implant production [7].

To successfully deploy metal AM technologies for the production of—in this case metallic hip implants—a set of challenges need to be acknowledged, understood and solved. In decision-making strategy, challenges are portrayed on the basis of technological, environmental, economic, organizational and personal aspects. The selection of the most promising AM technology to deploy is therefore of great importance and plays a significant role in the successful production and application of metal hip implants. The importance of the variability in AM technologies changes due to the needs of the different stakeholders and the dynamic business environment.

In this work, a hierarchical decision modelling (HDM) framework was deployed for the evaluation of AM technologies for the production of metallic hip implants to assess two AM technologies being used in the industry as well as research labs. The technologies evaluated were powder bed laser fusion (PBLF) and powder bed binder jetting (PBBJ).

By the use of this HDM methodology, it is expected to determine the highest potential among emerging technology alternatives in fulfilling the greatest efficacy of the chosen variables. The evaluation framework has been developed in accordance to literature review and expert judgements.

In the scope of this work, the hierarchical decision model (HDM) has been applied. The HDM framework is constituted on several levels each branching into subelements. These elements or variables are then compared in a pairwise fashion by chosen experts in the AM field who provide quantitative and qualitative evaluations. The assessment model has been designed as a data collection instrument and sent to the experts.

The outline of this proposed work is shown in Fig. 8.1. Firstly, the motivation and objective of this research study will be discussed, followed by a literature review on the existing and chosen technologies for AM in the field of titanium hip implant production.

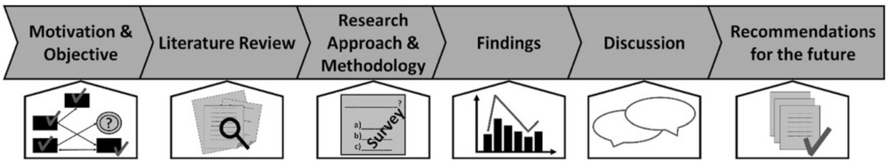

Fig. 8.1 Outline of the proposed work in this study

The undiscussed gaps from previous research or literature lead to the motivation of conducting the research study. The applied research methodology and data collection instrument design will be portrayed in the method section. The findings of the research will be represented, followed by a discussion section including a conclusion as well as the limitations and outlook of the research.

8.2 Literature Review

The use of additive manufacturing (AM) techniques portrays a new trend especially in the field of medicine. As it allows the fabrication of complex parts and assemblies in a single step, its application becomes widespread in various industries, reducing the need of specialized tooling and complex assembly processes due to manufacturing constraints. The short design-to-fabrication lifecycle provides faster implementation of ideas. In addition, reduced material waste as well as energy savings is an added incentive. AM technologies mainly use polymers, ceramics and metals, whereas nowadays, the latter shows the fastest growing trend [8].

As Forbes [9] states, AM is mainly used to prove a concept, manufacture prototypes, produce, educate, provide marketing samples and more. Thereby, Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Stereolithography (SLA) and Polyjet/Multijet are the mostly used 3D printing technologies used in 2016–2017 [9].

The promising use and popularity in industrial applications is generating a great shift in the market and can be detected by the increasing 3D printer sales among the years 2007–2015 ([10] with reference to Wohler's Report 2015; Gartner).

AM processes are applied not only in the field of automotive, aerospace or bioengineering [11, 12], but also in architecture, commercial products, consumer goods, consumer electronics, defence, dental, education, medical and mould industries that incorporate rapid prototyping (RP) processes [12].

The rising popularity of these technologies can be traced back recognizing its advantages. Though, all additive manufacturing methods also show disadvantages depending on their application field.

8.2.1 The Benefits and Shortcomings of 3D Printing

All different types of additive manufacturing processes show benefits as well as limitations or so-called shortcomings. The following points summarize the general advantages and disadvantages of such systems [13].

The benefits:

- Highly complex structures or parts can be designed with CAD which is then processed by the printer software. The CAD file can be changed due to design alterations.
- Customized products can be printed and thereby meet specific customer needs.
- A single printing station is needed to produce a part contributing to lower fixed costs.
- Time reduction due to fast manufacturing of the printed piece is ensured.
- Ease of use of the printing system. After having arranged the printer settings, the manufacturing process performs automatically.
- Waste materials are reduced since the printers cut the materials precisely.

The shortcomings:

- Less material and colour variety available (mainly metals and plastics used).
- Less precision (approximately between a range of 20 and 100 μm).
- Strength and endurance restrictions exist due to non-uniform processing (e.g. layer-by-layer).
- Large costs come up if extensive production runs take place.
- Post-processing consumes extra time since the products often need, for example, surface finishing and so on.

8.2.2 Additive Manufacturing Overview

Various additive manufacturing technologies exist nowadays and are used for industrial applications. Seven main categories of AM technologies can be differentiated by their characteristics into subcategories [13, 14].

The seven categories are:

- Vat photopolymerization branching in Stereolithography (SLA), Digital Light Processing (DLP) and Continuous Digital Light Processing (CDLP), all working with plastics.
- Material extrusion with its subcategory Fused Deposition Modelling (FDM), using composites and plastics.
- Material jetting including Material Jetting (MJ) using plastics, NanoParticle Jetting (NPJ) using metals and Drop On Demand (DOD) using wax.
- Binder jetting using gypsum, sand or metals.
- Powder bed fusion encompassing Multi Jet Fusion (MJF), Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS)/Selective Laser Melting (SLM) and Electron Beam Melting (EBM) using plastics or metals.
- Direct energy deposition including Laser Engineering Net Shape and Electron Beam Additive Manufacturing both for metals.
- Sheet lamination including Laminated Object Manufacturing (LOM) using composites and paper.

In the scope of this research work, the study was focused on the two metal AM technologies Laser Powder Bed Fusion and Powder Bed Binder Jetting due to its medical relevance for the titanium production.

8.2.3 Laser Powder Bed Fusion

Selective Laser Melting (SLM) is one of the major AM techniques in the powder bed fusion category and allows the use of materials such as aluminium alloys, titanium alloys, nickel alloys, iron alloys, cobalt alloys and copper alloys ([15] with references to Scudino et al., 2015, Kimura et al., 2017, Prashanth et al., 2014, Thijs et al., 2012 and 2010, Wu et al., 2017, Li et al., 2016, Zhu et al. 2016, Murr et al., 2012, Kempen et al., 2011, Lu et al., 2015, Kangarajah et al., 2013, Wang et al. 2016, Liverani et al., 2016, Lu et al., 2016, Zhou et al. 2015, Attar et al., 2015, Shi et al., 2016, Prashanth et al., 2016, Zhang et al., 2016).

Metal powder particles are fused during the melting phase layer-by-layer at a high temperature by the laser beam, to produce the desired part. To establish a proper melting condition, inert gases such as argon or nitrogen need to fill the build room. In addition to that, the pressure level is regulated to ensure that no oxygen is in the build chamber and fumes produced by the laser–material interaction [7, 15, 16].

It is also important to prevent the effect of thermal stress and warping of the part which can lead to premature part failure or other flaws through appropriate design and process parameter choices [17].

During the fabrication, a layer of metal powder is laid on the build bed platform, and the laser selectively sinters the powder in a scanning motion based on the area of the part corresponding to the manufacturing layer. The build bed is then lowered, and a new layer of powder is spread. This process continues layer-by-layer until the final part is produced. Support structures are needed in this process to ensure thermal conduction from overhanging features to the build plate in order to avoid over-melting and other associated defects. Once the fabrication is completed, the part needs to cool down. Post-processing covers the last phase of the part to be finished, as de-powdering, heat treatment, surface finishing and, in the case of implants, sterilization [16].

The advantage PBLF provides is the production of complex designs of the part with a high density which is difficult to accomplish with conventional processes. Therefore, the finished product can be brought to market with a specific design, geometry and weight customization. Often, PBLF is favoured over other AM technologies due to its ability to fabricate small production batches, ensuring less material losses [16, 18].

Various materials can be used for the PBLF process and the left powders can be re-used again, thus reducing the amount of material losses [15].

Compared to other AM processes, such as binder jetting for instance, PBLF is a slower process and requires high operating power. Moreover, the build sizes are restricted and the surfaces might need polishing due to inherent roughness. Effects such as cracking might appear since not all materials can handle large internal stresses which can happen due to the high thermal loading cycles occurring in the PBLF process [15].

8.2.4 Powder Bed Binder Jetting

As previously described, binder jetting is one of the major AM technologies that allows the use of metals such as aluminium, copper, iron, nickel, cobalt and ceramic alloys. For the process, two materials are deployed; the metal or ceramic powder and the binder material. The binder material serves the purpose of gluing the metal/ceramic powder together on the layers. Although the printing process is faster than PBLF, the metal parts manufactured via PBBJ require thermal post-processing, which can take more time and lead to the increase of costs for auxiliary thermal processing equipment such as specialized ovens. However, no heating is needed for the layer-by-layer fabrication phase, which reduces the system complexity and overall cost of this AM technology when compared to other metal AM processes that consume more energy. The printed part is porous and shows different mechanical properties than other AM processes, after the post-processing (thermal treatments, e.g., sintering, curing and cleaning from the remaining powder particles) [13, 15].

Thus, in general, PBLF might be favoured over binder jetting since the PBLF-printed part provides stronger mechanical properties, though when it comes to achieving higher durability, metal binder jetting is a better choice [19].

Another advantage of binder jetting is the ability to print in full colours and attain lightweight structures to a finer degree when compared to laser process [19, 20].

When it comes to making a decision in order to choose a technology that suits the needs of the stakeholders the most, the available technologies need to be assessed among several criteria. In literature though, there is often the focus on technological or economic considerations [15]. This rather limited perspective gave rise to the idea of broadening the selection criteria to incorporate more considerations of the AM technologies.

Therefore, the following perspectives or criteria from the literature in Table 8.1 have been extended by expert considerations and will be portrayed further in the next section "model development".

8.3 Research Approach and Methodology

8.3.1 Model Development

When it comes to assessing technologies, the chosen framework contains seven steps that describe the requirements to be fulfilled.

Table 8.1 Systematic overview of the perspectives

Perspectives/ criteria	Objectives	Goals
Technological	Increasing technical performance and thereby enhancing efficacy of the process	• Raise system reliability, flexibility and effectivity • Increase the persistence ability of the manufacturing process
Environmental	Reduction of environmentally harmful/negative effects on the ecosystem	• Increase potential for eco-friendly system and resource use
Economic	Reduction of system and training costs	• Increasing efficient monetary distribution and decrease overall costs • Reducing maintenance, lifecycle and training costs
Organizational	Enhancing operational entities (such as flexibility, traceability and certification)	• Increase safety in manufacturing process • Increase availability of the product and technology • Increase the potential of high-quality standard feasibility • Increase the transparency for controlling and tracing processes during the manufacturing and delivering of the end product
Personal	Increasing stakeholders' interest and satisfaction level in using a specific technology for metallic hip implant production	• Improve ease of use of the manufacturing method and its maintenance • Ensuring a safe use of the equipment necessary for the part production

Firstly, step 1 depicts the identification and assessment of the problem in terms of needs, gaps and current capabilities. Step 2 reveals the determination of technology acquisition channels, disruptive as well as available technologies, to assess the existing environment. Furthermore, the data availability needs to be evaluated in step 3. As some data can be identified objectively (as for instance costs), on the contrary, some cannot be measured quantitatively which is the reason to attain expert judgements on subjective matters. The market and competitive products or processes need to be analysed and governmental regulations are considered in step 4. This is followed by the determination of the evaluation methodology in step 5 and the criteria that need to be chosen. These criteria should be given weights of importance objectively and subjectively. Step 6 involves the comprehension of the stack of technologies. Technology clusters and problem solutions have to be considered and portrayed clearly. This step helps to identify the technology options. After having decided for a specific method to gather and evaluate the data on each criterion, the tasks have to be executed, and the results are recorded in the last step. In addition to that, the results need to be interpreted and a recommendation needs to be made [21]. All steps are summarized in Fig. 8.2.

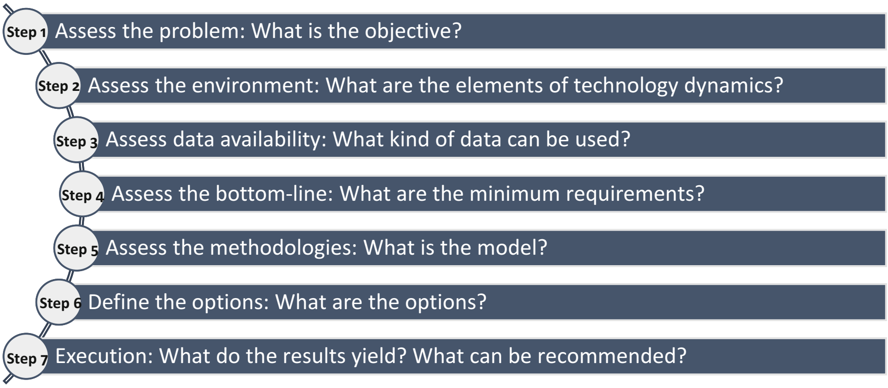

Fig. 8.2 Summary of technology assessment and acquisition [21]

This approach draws a close similarity to Cleland and Kocaoglu's [22] decision hierarchy model. After having defined all steps (mission, objectives, goals, strategies and actions), a relative value or priority needs to be determined on each objective, since the identified problem incorporates a multicriteria decision model.

The hierarchical decision model (HDM) concept portrays a clear structure among the variables and criteria that both technologies (laser powder bed fusion and powder bed binder jetting) have in common and can be compared with each other on multiple levels. Moreover, the reliability of each expert's judgement can be measured with the so-called inconsistency score.

HDM not only allows the quantification of multiple factors that are objective and subjective evaluations but also assigns prioritization among interrelated elements to assist with complex decision makings in the managerial perspective [22].

The model in this study was developed after the depicted steps (model development, model validation and model quantification). It is based on a literature review and was extended by experts' experiences in the field of laser powder bed fusion and powder bed binder jetting [21].

The mission, objectives (criteria), goals (variables) and alternatives constitute the four levels of the model of this study, evolving into 5 main criteria, 25 variables and 2 alternative technologies (see Fig. 8.3).

The chosen experts working in the field of additive manufacturing provide knowledge on the alternative technologies and can therefore judge about the relative importance of the presented criteria and variables.

The decision makers had to follow the instructions of the hierarchical decision model and undergo a pairwise comparison among the criteria and variables. A software has been developed by the department of engineering and technology management at the Portland State University called pairwise comparison method (PCM), to evaluate the experts' judgements on the criteria and variables.

Including all considerations, five main criteria were identified, each incorporating sublevel criteria or so-called variables. In order to clearly make the participant understand the procedure and pairwise comparison, definitions on each criterion and variable have been given.

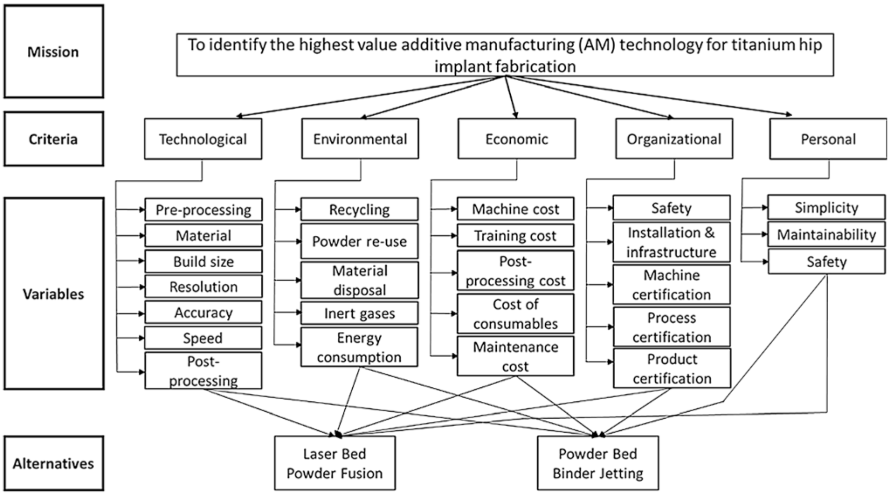

Fig. 8.3 Assessment model

This approach and similar criteria can be found in different contexts such as the renewable energy sector (technical, economic, environmental, social, geographical, political, performance, functional, etc.) [23–26].

The first criterion in this study is "technological" which is defined as factors that impact technical performance to produce a high-quality product. Its variables have been defined as the following:

- Pre-processing considerations: The preparatory processes before starting the manufacturing process of the hip implant. This includes setting up the print files in the software build environment, loading up materials and getting the machine ready for a new printing cycle.
- Material considerations: For the context of this data collection, only biocompatible titanium and titanium alloys are considered.
- Build size considerations: The build size envelope required for printing the part or a batch of parts.
- Resolution considerations: The smallest achievable feature size based on machine capabilities.
- Accuracy considerations: The extent to which a printed part matches the design (within a tolerance range).
- Speed considerations: The speed of producing the product as a batch or individually.
- Post-processing considerations: Includes any action required to turn the manufactured part into a finished product, including de-powdering, machining, surface finishing, heat treatment and sterilization.

The second criterion is "environmental" which is defined as factors that have an influence on the environment and the ecosystem. Its variables have been defined as:

- Recycling considerations: The ease of deploying processes to recycle materials that have reached their end-of-life span as specified by the process certification criteria.
- Powder re-use considerations: Reveals the ability to use the powder again in the process, with specific blend ratios of virgin to used powder.
- Material disposal considerations: Captures the waste materials that are left after the process, which cannot be used in the process again.
- Inert gases considerations: Describes the rate of use of inert gases during the fabrication process as well as during any post-processing stages.
- Energy consumption considerations: This point portrays the energy that is consumed for processing the part or batch of parts.

The third criterion is "economic" which describes factors that refer to the cost of technological deployment and use, staff training and lifecycle costs. Variables are defined as:

- Machine cost considerations: Captures the total cost of the machine, auxiliary equipment such as furnaces, de-powdering station, powder management ancillary stations and so on.
- Cost of consumables: The cost associated with general consumables necessary to manufacture the finished product. Such consumables may be operator safety gear, process environment gases, build plates, brushes, gloves, chemicals or solutions required to run the machine.
- Training cost considerations: Describes the cost associated with the training of the staff to use the technology properly.
- Post-processing cost considerations: Reveals the cost for post-processing steps necessary to produce the finished printed piece.
- Maintenance cost considerations: Describes the cost for meeting general maintenance requirements.

The fourth criterion is "organizational" which can be defined as factors that depend on certification and traceability processes, safety issues and infrastructural aspects. This criterion involves the following variables:

- Safety considerations: This aspect covers the safety measurements/requirements for proper handling of the technology.
- Installation and infrastructure considerations: Describes the space requirements for installing and running the equipment, as well as the involvement of technicians in the initial setup and installation of the equipment.
- Machine certification considerations: Describes the compliance conditions applicable to the equipment used to manufacture the products to enable machine setup traceability and machine performance quality analytics.
- Process certification considerations: Describes the compliance conditions applicable to the process (including supply chain) to enable process traceability and process performance quality analytics.
- Product certification considerations: Describes the compliance conditions applicable to the product to enable product traceability and part performance quality analytics.

The fifth criterion is "personal" and is defined as factors that impact the ease of use and satisfaction level of the process operator. The variables are defined as:

- Simplicity: Captures the perceived ease of use in terms of physical activity needed to manufacture parts using the technology system selected.
- Maintainability: Describes the perceived ease of maintenance of the technology to maintain performance/certification criteria.
- Safety: Describes how safe the equipment is to use in a general manufacturing environment.

All these variables are then evaluated referring to the two technologies laser powder bed fusion and powder bed binder jetting. Figure 8.3 shows an overview of the final version of the technology assessment model.

8.3.2 Data Collection Instrument Design

To effectively reduce the amount of effort and time spent on the data collection instrument, a brief description of the method and purpose of the evaluation was given in the beginning of each part. After having asked for the experts' consent to participate in the study, they could indicate their job position in the data collection document to let the researcher gain a better overview of the experts' background diversities. Furthermore, the experts should specify which technology or technologies they have experience with and provide expertise in evaluating them.

To reduce misunderstandings, each section of the data collection reveals the research goal and introduces the participant with the current criteria and its definitions.

8.3.3 Selecting and Reaching the Experts

The experts were chosen based on the matching capability of their knowledge and experience in this research field, on their availability as well as consent to participate in the study.

Their knowledge and experience can be recognized on existing publications and (years of) work with the applied technology options in their companies.

To reach out and increase the probability of experts' willingness to participate in the study, factors such as time spent as well as effort put into the evaluation need to be considered. Therefore, the data collection instrument has been designed in a user-friendly structure. No specific software to evaluate the data has been needed, as it was sent via an e-mail in pdf format to the experts. Furthermore, the approximate duration for the total assessment has been indicated in the e-mail.

It is moreover important to awaken the interest and motivation of the experts in participating in the current study and pointing out its relevance and validity for their

Table 8.2 Evaluation overview

	Job position	Chosen technology
Evaluation 1	Research director, orthopaedic biomechanics lab, hospital	Powder bed binder jetting
Evaluation 2	Post-doctoral fellow, multiscale additive manufacturing lab	Powder bed binder jetting
Evaluation 3	Mechanical engineer, project leader	Laser bed powder fusion
Evaluation 4	Post-doctoral fellow, multiscale additive manufacturing lab	Laser bed powder fusion
Evaluation 5	Assistant professor	Laser bed powder fusion
Evaluation 6	Assistant professor	Powder bed binder jetting
Evaluation 7	Research engineer	Laser bed powder fusion

own work environments [27]. This aspect can be identified by contacting and asking for the experts' participation interest and willingness in an e-mail. General information about the validity and applied method for the data collection have been explained within the e-mail.

8.3.4 Data Collection

The data collection document was sent to the experts in the field of metal manufacturing, with experience relevant to implant fabrication, via e-mail to gather the data of their assessment. Table 8.2 shows an overview of the number of evaluations according to their job positions and evaluated technologies.

8.4 Findings

In total, seven evaluations (four on laser powder bed fusion and three on powder bed binder jetting) have been obtained.

Table 8.3 shows an overview of all attained data for each criterion after the HDM software analysis from the seven evaluations for the two technologies laser powder bed fusion and powder bed binder jetting. The mean values of each variable's relative weight for each technology have been depicted in the two right columns of Table 8.3.

Summing up the variable weights for each category, economic considerations yielded 0.301 and presents the most important consideration judged by the experts. Secondly, the weight of technological considerations follow with 0.251, the weight of organizational considerations with 0.217, the weight of personal considerations with 0.161 and lastly, the weight of environmental considerations with 0.080.

Table 8.3 Overview of the relative weights on the variables

Variables	Evaluation 1	Evaluation 2	Evaluation 3	Evaluation 4	Evaluation 5	Evaluation 6	Evaluation 7	Variable weights	
Pre-processing	0.01	0.05	0.01	0	0.01	0	0.04	0.017	
Material	0	0.03	0.05	0.03	0.01	0.01	0.07	0.029	
Build size	0.05	0.03	0.01	0.01	0.02	0	0.07	0.027	
Resolution	0.01	0.08	0.05	0.01	0.04	0.02	0.07	0.040	0.251
Accuracy	0.01	0.11	0.06	0.07	0.03	0.03	0.12	0.061	
Speed	0.01	0.05	0.01	0.02	0.05	0.01	0.01	0.023	
Post-processing	0.06	0.08	0.04	0.02	0.07	0	0.11	0.054	
Recycling	0.01	0	0.03	0.01	0.02	0.01	0.02	0.014	
Powder re-use	0.01	0.01	0.07	0.01	0.05	0.01	0.02	0.026	
Material disposal	0.01	0	0.03	0.01	0.03	0	0.02	0.014	0.080
Inert gases	0	0.01	0	0	0.04	0	0.01	0.009	
Energy consumption	0	0.01	0.01	0	0.06	0.01	0.03	0.017	
Machine cost	0.05	0.03	0.15	0.03	0.07	0.21	0.04	0.083	
Cost of consumables	0.01	0.08	0.06	0.07	0.05	0.07	0.04	0.054	
Training cost	0.01	0.03	0.03	0.01	0.04	0.03	0.04	0.027	0.301
Post-processing cost	0.02	0.11	0.04	0.14	0.07	0.06	0.04	0.069	
Maintenance cost	0.04	0.08	0.07	0.09	0.06	0.1	0.04	0.069	
Safety	0.08	0.05	0.1	0.05	0.04	0.19	0.04	0.079	
Installation and infrastructure	0.02	0.01	0	0.06	0.02	0.02	0.02	0.021	
Machine certification	0.03	0.02	0.01	0.05	0.02	0.02	0.02	0.024	0.217
Process certification	0.09	0.04	0.03	0.05	0.03	0.02	0.02	0.040	
Product certification	0.14	0.02	0.06	0.05	0.05	0.03	0.02	0.053	
Simplicity	0.11	0.01	0.01	0.04	0.05	0.03	0.02	0.039	
Maintainability	0.08	0.02	0.04	0.08	0.04	0.02	0.02	0.043	0.161
Safety	0.14	0.06	0.04	0.1	0.04	0.11	0.07	0.080	
Inconsistency	0.07	0.08	0.12	0.06	0.02	0.12	0.04	0.073	

Comparing the two technologies among the variables (Fig. 8.4), the highest mean value for technological considerations is "accuracy" and the lowest mean value is "pre-processing".

In environmental considerations, the mean value of "powder re-use" shows highest importance for both technologies and the lowest importance for "inert gases".

Among the cost considerations, the "machine cost" mean value reveals the greatest weight among the variables of cost and "training cost" the least weight.

In organizational considerations, the variable "safety" has been deemed with greatest importance and "installation and infrastructure considerations" with lowest importance.

The assessment for personal considerations showed that also "safety" presents the highest importance variable and "simplicity" the lowest weight.

Figure 8.4 depicts the distribution of the mean values for each variable.

The inconsistency values are indicated in the last line of Table 8.3 with 0.073 for the two technologies. In general, the inconsistency values state the quality of the calculated weights, whereas its approximate norm should be between 0.0 and 0.1 to show consensus among the experts' judgements [28].

If an inconsistency value is greater than 0.1, the expert would have been asked to reconsider the given evaluation until a value below 0.1 had been achieved [29].

In this study, only evaluations 3 and 6 show an inconsistency level slightly higher than 0.1, whereas all other evaluations are below 0.1.

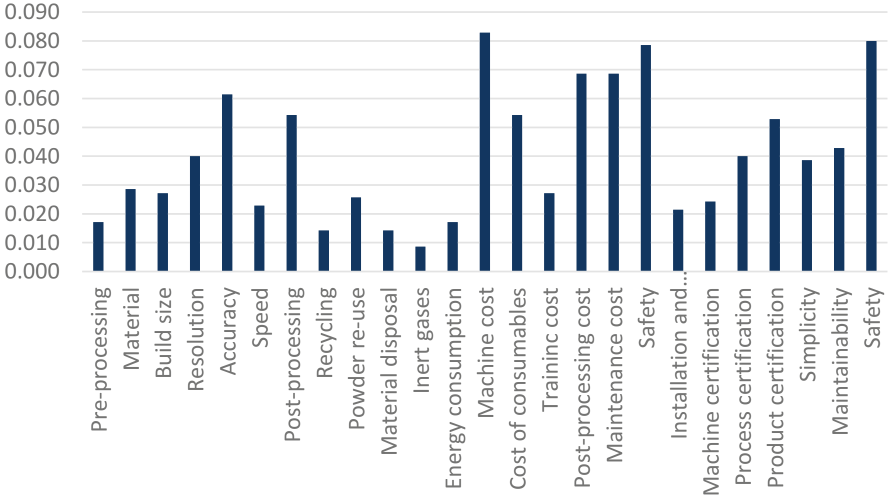

Fig. 8.4 Mean value distribution of both technology variables

Due to limitations in time and reachability of the experts, evaluations 3 and 6 could not be reconsidered by the experts.

Table 8.4 shows the scaled values for both technologies, attained with an expert evaluation providing knowledge in both technologies. As being shown in different research studies using this methodology, the expert can distribute on different scales, such as 0–100, 0–10 or else, in different intervals [30–32].

The experts for this research study assessed both technologies on each variable on a scale from 0 to 10, where 0 means least importance and 10 means highest importance/priority. In the next step, the mean values of each technology are multiplied with their scaled values to obtain the global weights on each technology. Summing up the global weights, the total scores in the bottom line are calculated. The total scores show the overall results of the technology assessment; on a scale from 0 to 10, the value closer to 10 shows the technology with greater importance and preference, considering all criteria and variables. In this case, powder bed binder jetting is the technology that achieved higher priority assessment overall.

8.5 Discussion and Outlook

Comparing the results of the two technologies shows that powder bed binder jetting has obtained higher importance overall than laser powder bed fusion, but only by a close margin. When it comes to the fabrication of metallic hip implants, powder bed binder jetting is the technology that fulfils the five main considerations (technological, environmental, economic, organizational and personal) with greater potential. The weight ranking among the five criteria shows that economic considerations are most

Table 8.4 Global weightings and total scores of the technologies

	Scaled values for laser fusion	Scaled values for binder jetting	Variable weights	Final score: laser fusion	Final score: binder jetting
Pre-processing	2.00	2.50	0.017	0.034	0.043
Material	6.66	6.17	0.029	0.190	0.176
Build size	2.80	3.00	0.027	0.076	0.081
Resolution	7.00	7.17	0.040	0.280	0.287
Accuracy	7.34	8.44	0.061	0.451	0.518
Speed	3.44	4.67	0.023	0.079	0.107
Post-processing	5.84	3.17	0.054	0.317	0.172
Recycling	5.75	6.00	0.014	0.082	0.086
Powder re-use	8.00	6.75	0.026	0.206	0.174
Material disposal	5.75	4.00	0.014	0.082	0.057
Inert gases	1.75	3.25	0.009	0.015	0.028
Energy consumption	3.75	5.00	0.017	0.064	0.086
Machine cost	7.50	8.00	0.083	0.621	0.663
Cost of consumables	5.25	4.50	0.054	0.285	0.244
Training cost	3.25	2.25	0.027	0.088	0.061
Post-processing cost	3.50	4.25	0.069	0.240	0.291
Maintenance cost	5.50	7.00	0.069	0.377	0.480
Safety	9.00	9.00	0.079	0.707	0.707
Installation and infrastructure	1.00	3.25	0.021	0.021	0.070
Machine certification	3.25	4.00	0.024	0.079	0.097
Process certification	5.50	4.00	0.040	0.220	0.160
Product certification	6.25	4.75	0.053	0.330	0.251
Simplicity	2.00	4.50	0.039	0.077	0.174
Maintainability	6.50	2.00	0.043	0.279	0.086
Safety	6.50	8.50	0.080	0.520	0.680
Total scores				5.722	5.779

important when acquiring an AM technology. Due to financial limitations in companies or research labs, the cost of the machine is the main aspect to decide for and pick a technology. The high costs of the machines often pose a barrier to the technology acquisition and should be decreased to ensure greater access in the market. As training costs showed the lowest weight ranking among economic considerations, it can be deemed a great potential of improvement for industrial purposes.

Technological considerations show second highest ranking among all assessed considerations. The fabrication of specific parts or batches and thereby the implementation of details can be attained by high accuracy settings. This is especially important for producing dense medical implants and providing high-quality products. Pre-processing considerations pose the greatest potential for enhancement among the variables in this category.

In organizational considerations, safety matters were prioritized as handling the technology correctly poses greatest importance. Although the processes are automated, the right handling of materials and correct use of the technology system, as well as operator safety have to be guaranteed. The low weighting of installation and infrastructural considerations on the contrary portray the need for desirable advancement.

Safety considerations have also been given greatest weight in the personal category. Though, for the laser fusion technology, the variable "simplicity" has the lowest weight, it is posing potential for development and "maintainability" for the binder jetting technology.

Environmental considerations show the least importance among the five criteria as the experts' concerns are rather concentrated on the re-use of powder. This reveals that the still existing gaps of not being fully able to re-use all of the powder in a process should be bridged in the future, thus reducing the amount of waste materials. The least weighting among this category has been depicted for inert gas considerations. This illustrates a potential for further development for both technologies.

Moreover, the relatively low inconsistency levels show that there is general agreement among the experts' assessments. Thus, the binder jetting technology has been proven to be a better option to fabricate metallic hip implants. On a broader level, PBBJ is not yet as popular in the industry as PBLF which is due to the lacking understanding on how to control part functional properties using the post-processing thermal sintering. Generally saying, it is challenging to make exact quantitative predictions for sintering reactions because they rely upon the relative solubility of the medium, the relative surface energy as well as the relative diffusion rates [33].

8.5.1 Scenario Analysis

Assuming different scenarios for criteria weightings, one can obtain that an emphasis or priority on technological considerations would yield a higher final score of the technology laser powder bed fusion. Thus, laser powder bed fusion would be the greater favoured technology due to its highly equipped technological features (see Table 8.5).

If the priority ranking for environmental considerations was highest (in scenario 2, see Table 8.6) again, laser powder bed fusion would have attained higher final scores than powder bed binder jetting. Scenario 3 would show an emphasis on organizational considerations which would also yield to a higher final score of laser powder bed fusion (see Table 8.7).

Only scenario 4 (highest priority on economic considerations) and scenario 5 (highest priority on personal considerations) would show that powder bed binder jetting is the better option for the fabrication of metallic hip implants (see Tables 8.8 and 8.9). These different scenarios present the outcome of differently weighted criteria preferences on the selection of the better suiting technology option.

All in all, if experts had favoured technological, environmental or organizational considerations more, the better technology option would have been laser powder bed fusion, whereas a higher priority weighting on economic or personal considerations yields a selection preference of powder bed binder jetting.

Table 8.5 Scenario 1: Criteria weight emphasis on technological considerations

Variables	Scaled values for laser fusion	Scaled values for binder jetting	Variable weights	Final score: laser fusion	Final score: binder jetting
Pre-processing	2.00	2.50	0.068	0.137	0.171
Material	6.66	6.17	0.114	0.758	0.702
Build size	2.80	3.00	0.108	0.303	0.324
Resolution	7.00	7.17	0.159	1.116	1.143
Accuracy	7.34	8.44	0.245	1.796	2.066
Speed	3.44	4.67	0.091	0.313	0.425
Post-processing	5.84	3.17	0.216	1.263	0.686
Recycling	5.75	6.00	0.000	0.000	0.000
Powder re-use	8.00	6.75	0.000	0.000	0.000
Material disposal	5.75	4.00	0.000	0.000	0.000
Inert gases	1.75	3.25	0.000	0.000	0.000
Energy consumption	3.75	5.00	0.000	0.000	0.000
Machine cost	7.50	8.00	0.000	0.000	0.000
Cost of consumables	5.25	4.50	0.000	0.000	0.000
Training cost	3.25	2.25	0.000	0.000	0.000
Post-processing cost	3.50	4.25	0.000	0.000	0.000
Maintenance cost	5.50	7.00	0.000	0.000	0.000
Safety	9.00	9.00	0.000	0.000	0.000
Installation and infrastructure	1.00	3.25	0.000	0.000	0.000
Machine certification	3.25	4.00	0.000	0.000	0.000
Process certification	5.50	4.00	0.000	0.000	0.000
Product certification	6.25	4.75	0.000	0.000	0.000
Simplicity	2.00	4.50	0.000	0.000	0.000
Maintainability	6.50	2.00	0.000	0.000	0.000
Safety	6.50	8.50	0.000	0.000	0.000
Total scores				5.686	5.517

8.5.2 Limitations

The experts' evaluation of the model provides a broad range of results. The experts have been chosen to assess the technology or technologies they have knowledge about and experience within their professional lives. This usually shows that experts have used one specific technology in their companies over several years and might not be able to assess all two technologies, which were suggested to evaluate in this study, to the same extent. Thus, experts with different perspectives, expertise and companies have been contacted to participate in the study and therefore accomplish the technology assessment study with greater variety. Moreover, three experts gave their evaluation on binder jetting and four on laser fusion. An equal amount of

Table 8.6 Scenario 2: Criteria weight emphasis on environmental considerations

Variables	Scaled values for laser fusion	Scaled values for binder jetting	Variable weights	Final score: laser fusion	Final score: binder jetting
Pre-processing	2.00	2.50	0.000	0.000	0.000
Material	6.66	6.17	0.000	0.000	0.000
Build size	2.80	3.00	0.000	0.000	0.000
Resolution	7.00	7.17	0.000	0.000	0.000
Accuracy	7.34	8.44	0.000	0.000	0.000
Speed	3.44	4.67	0.000	0.000	0.000
Post-processing	5.84	3.17	0.000	0.000	0.000
Recycling	5.75	6.00	0.179	1.027	1.071
Powder re-use	8.00	6.75	0.321	2.571	2.170
Material disposal	5.75	4.00	0.179	1.027	0.714
Inert gases	1.75	3.25	0.107	0.188	0.348
Energy consumption	3.75	5.00	0.214	0.804	1.071
Machine cost	7.50	8.00	0.000	0.000	0.000
Cost of consumables	5.25	4.50	0.000	0.000	0.000
Training cost	3.25	2.25	0.000	0.000	0.000
Post-processing cost	3.50	4.25	0.000	0.000	0.000
Maintenance cost	5.50	7.00	0.000	0.000	0.000
Safety	9.00	9.00	0.000	0.000	0.000
Installation and infrastructure	1.00	3.25	0.000	0.000	0.000
Machine certification	3.25	4.00	0.000	0.000	0.000
Process certification	5.50	4.00	0.000	0.000	0.000
Product certification	6.25	4.75	0.000	0.000	0.000
Simplicity	2.00	4.50	0.000	0.000	0.000
Maintainability	6.50	2.00	0.000	0.000	0.000
Safety	6.50	8.50	0.000	0.000	0.000
Total scores				5.616	5.375

participants for both technologies might have given access to understand the technologies on a more balanced scale.

All of the experts have been asked to participate in the research study with their own will and were informed about anonymity.

The technology assessment results show current findings and might differ in the future. The chosen considerations "technological, environmental, economic, organizational and personal" and subconsiderations/variables may vary in time as well as technology alternatives, as other technologies can be developed to fabricate metallic hip implants. Therefore, the best alternative, as shown in the findings section, reveals the current standpoint but might not be the optimal choice of technology for the fabrication of titanium hip implants in future times.

Another factor that should be considered in this context is the value for the market. Once receiving more data and feedback from the success rates of the applied

Table 8.7 Scenario 3: Criteria weight emphasis on organizational considerations

Variables	Scaled values for laser fusion	Scaled values for binder jetting	Variable weights	Final score: laser fusion	Final score: binder jetting
Pre-processing	2.00	2.50	0.000	0.000	0.000
Material	6.66	6.17	0.000	0.000	0.000
Build size	2.80	3.00	0.000	0.000	0.000
Resolution	7.00	7.17	0.000	0.000	0.000
Accuracy	7.34	8.44	0.000	0.000	0.000
Speed	3.44	4.67	0.000	0.000	0.000
Post-processing	5.84	3.17	0.000	0.000	0.000
Recycling	5.75	6.00	0.000	0.000	0.000
Powder re-use	8.00	6.75	0.000	0.000	0.000
Material disposal	5.75	4.00	0.000	0.000	0.000
Inert gases	1.75	3.25	0.000	0.000	0.000
Energy consumption	3.75	5.00	0.000	0.000	0.000
Machine cost	7.50	8.00	0.000	0.000	0.000
Cost of consumables	5.25	4.50	0.000	0.000	0.000
Training cost	3.25	2.25	0.000	0.000	0.000
Post-processing cost	3.50	4.25	0.000	0.000	0.000
Maintenance cost	5.50	7.00	0.000	0.000	0.000
Safety	9.00	9.00	0.362	3.259	3.259
Installation and infrastructure	1.00	3.25	0.099	0.099	0.321
Machine certification	3.25	4.00	0.112	0.364	0.448
Process certification	5.50	4.00	0.184	1.014	0.737
Product certification	6.25	4.75	0.244	1.522	1.157
Simplicity	2.00	4.50	0.000	0.000	0.000
Maintainability	6.50	2.00	0.000	0.000	0.000
Safety	6.50	8.50	0.000	0.000	0.000
Total scores				6.257	5.922

technologies for titanium hip implant fabrication and insertion into the patients, a better understanding for gaps and improvements can be developed. Thus, a change in market needs can impact the value of the findings of this research work.

Last but not least, it needs to be considered that this research work has only focused on titanium implants only placed in the hips. More research can be conducted in the field of different metallic implants in terms of materials or application fields such as implants for the knees, shoulders or other parts of the body.

Furthermore, this research concentrated on the two metal additive manufacturing technologies laser powder bed fusion and powder bed binder jetting, both emerging in the production of medical titanium implants. The experts' technology assessment has shown that PBBJ represents a slightly better technology choice compared to PBLF and additionally highlights the potential for improvement in both technologies' variables for enhanced accomplishment of stakeholders' needs. However, other

Table 8.8 Scenario 4: Criteria weight emphasis on economic considerations

Variables	Scaled values for laser fusion	Scaled values for binder jetting	Variable weights	Final score: laser fusion	Final score: binder jetting
Pre-processing	2.00	2.50	0.000	0.000	0.000
Material	6.66	6.17	0.000	0.000	0.000
Build size	2.80	3.00	0.000	0.000	0.000
Resolution	7.00	7.17	0.000	0.000	0.000
Accuracy	7.34	8.44	0.000	0.000	0.000
Speed	3.44	4.67	0.000	0.000	0.000
Post-processing	5.84	3.17	0.000	0.000	0.000
Recycling	5.75	6.00	0.000	0.000	0.000
Powder re-use	8.00	6.75	0.000	0.000	0.000
Material disposal	5.75	4.00	0.000	0.000	0.000
Inert gases	1.75	3.25	0.000	0.000	0.000
Energy consumption	3.75	5.00	0.000	0.000	0.000
Machine cost	7.50	8.00	0.275	2.065	2.202
Cost of consumables	5.25	4.50	0.180	0.947	0.812
Training cost	3.25	2.25	0.090	0.293	0.203
Post-processing cost	3.50	4.25	0.228	0.797	0.968
Maintenance cost	5.50	7.00	0.228	1.254	1.596
Safety	9.00	9.00	0.000	0.000	0.000
Installation and infrastructure	1.00	3.25	0.000	0.000	0.000
Machine certification	3.25	4.00	0.000	0.000	0.000
Process certification	5.50	4.00	0.000	0.000	0.000
Product certification	6.25	4.75	0.000	0.000	0.000
Simplicity	2.00	4.50	0.000	0.000	0.000
Maintainability	6.50	2.00	0.000	0.000	0.000
Safety	6.50	8.50	0.000	0.000	0.000
Total scores				5.356	5.781

AM technologies, such as electron beam melting for instance, can be considered and compared to broaden the applicability of the results and understanding.

The variety of experts can be extended by reaching out to different regions in the world. The participants in this study are mainly from the North American region, as it is one of the most growing markets in metal AM worldwide. Thereby, stakeholder diversity (including physicians/surgeons or end-consumers such as patients) could yield a more global and extensive perspective on deploying an AM technology assessment.

Table 8.9 Scenario 5: Criteria weight emphasis on personal considerations

Variables	Scaled values for laser fusion	Scaled values for binder jetting	Variable weights	Final score: laser fusion	Final score: binder jetting
Pre-processing	2.00	2.50	0.000	0.000	0.000
Material	6.66	6.17	0.000	0.000	0.000
Build size	2.80	3.00	0.000	0.000	0.000
Resolution	7.00	7.17	0.000	0.000	0.000
Accuracy	7.34	8.44	0.000	0.000	0.000
Speed	3.44	4.67	0.000	0.000	0.000
Post-processing	5.84	3.17	0.000	0.000	0.000
Recycling	5.75	6.00	0.000	0.000	0.000
Powder re-use	8.00	6.75	0.000	0.000	0.000
Material disposal	5.75	4.00	0.000	0.000	0.000
Inert gases	1.75	3.25	0.000	0.000	0.000
Energy consumption	3.75	5.00	0.000	0.000	0.000
Machine cost	7.50	8.00	0.000	0.000	0.000
Cost of consumables	5.25	4.50	0.000	0.000	0.000
Training cost	3.25	2.25	0.000	0.000	0.000
Post-processing cost	3.50	4.25	0.000	0.000	0.000
Maintenance cost	5.50	7.00	0.000	0.000	0.000
Safety	9.00	9.00	0.000	0.000	0.000
Installation and infrastructure	1.00	3.25	0.000	0.000	0.000
Machine certification	3.25	4.00	0.000	0.000	0.000
Process certification	5.50	4.00	0.000	0.000	0.000
Product certification	6.25	4.75	0.000	0.000	0.000
Simplicity	2.00	4.50	0.240	0.479	1.078
Maintainability	6.50	2.00	0.266	1.730	0.532
Safety	6.50	8.50	0.497	3.230	4.224
Total scores				5.439	5.834

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Chapter 9
An Evaluation Model of Business Intelligence for Enterprise Systems with Interval-Valued Intuitive Fuzzy ARAS

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9.1 Introduction

Nowadays, with increasing competition among businesses and the massive developments of information technology (IT), it may be claimed that the survival and success of enterprises are more tied with efficient and effective utilization of technologies than ever [1]. Many enterprises have recently realized that the efficient use of information capabilities and new technologies is by far the best way to enhance their success and profitability in the global market [2]. The lack of attention to the potential of IT for corporate sustainability would expose companies to a wide range of challenges such as massive amounts of raw data, scarcity of information and knowledge, and/or lack of access to appropriate documents [3]. In such circumstances, macro-organizational decisions are generally made based on top management experiences, and thereby, the risk of failure and unsuccessful decisions can be duplicated [3]. Over the years, management information systems including management information system (MIS), decision support system (DSS), expert system (ES), executive information system (EIS), and so on have widely supported companies with their decisions; however, a key missing capability to manage decisions for emergencies, block out the competition, collect information from different views, and conduct extensive information analysis is the major cause of failure to adequately meet the needs of enterprise decision-makers [4]. The intensive and complex changes in environment have led companies toward the use of novel methods. And so, new integrated systems have gradually replaced the traditional management information systems that were ineffective due to their island systems and network-independent functions [5, 6].

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In recent years, there has been great interest in business intelligence (BI) as a vital program that aims to support an integrated environment for management decision-making, ensure adequate insight into organizational processes, strategies, and operations, and improve organization performance [7–9]. The concept of Business Intelligence was first developed by Dresner in 1989 and defined as a series of computer-based methods for the improvement of business decisions [10]. Now, it describes the concurrent meaning of processes and products [11]. Accordingly, BI can be explained as a systematic and organized process to collect and transmit data from/among various sources. Further, from a product-oriented viewpoint, this concept can be considered as information and knowledge which describe business environment, organization, market, customers, and so on and allow a reasonable certainty prediction of the behavior of competitors, suppliers, customers, trend of technological developments, products, and services [9, 12]. However, because of a variety of reasons such as inability to distinguish sensitive information, lack of optimal gathering of external information, need for handling storage, classification, process, and analysis of huge data, and improper use of information, the importance of business intelligence is now more palpable than it has even been before. Therefore, BI can be regarded as one of the fundamental components of information system resources and also as an essential requirement for an organization's success [13].

The growing tendency to use smart devices in commercial systems has increased the practical necessity for the BI evaluation of enterprise systems [5]. An assessment of the efficiency and performance of information systems is a key element for a successful implementation [3]. Organizations spend hundreds of millions of dollars annually on the implementation and maintenance of their information systems [14]. It is, therefore, of great interest to assess the levels of business intelligence as a measure of organizational success in responding to the needs of users.

Despite the importance of this field, there has been a little research on the assessment of enterprise-level business intelligence [3]. Moreover, the majority of studies consider business intelligence independent from other enterprise systems [5, 15]. Therefore, it seems critical to develop an assessment model of business intelligence for enterprise systems. The need for measuring all the pros and cons of BI, as well as the presence of multiple factors considered both by users and experts in the field has changed the business evaluation into a multiple attribute decision-making problem [3]. For this reason, the current study seeks to develop a modern evaluation approach of business intelligence for enterprise systems by using new multiple attribute decision making (MADM) techniques. Unlike previous research, the application of interval-valued fuzzy ARAS method, one of the new MADM techniques regarding current uncertainties in decision-making, highlights the additional advantage of this study. Considering uncertain environment that we confront in this case, we use interval-valued fuzzy ARAS in this article.

From the BI viewpoint, this paper investigates five enterprise systems based on a total of 34 indicators within the proposed framework. The "Literature Review" discusses a number of studies conducted on business intelligence. Then, the

"Methodology" includes detail descriptions of the research steps and the interval-valued fuzzy ARAS method. Next, the assessment process based on the model is presented in the "Results". Finally, the "Conclusion and Recommendations" develops the analysis.

9.2 Literature Review

As stated before, the concept of BI has recently received a remarkable amount of academic interest due to major needs of organizations to make sound decisions and appropriate use of information. Differences in views and attitudes toward this concept have led to a wide variety of definitions in the literature. BI is an umbrella term, covering a broad set of function, developed by Dresner in 1989 as a set of concepts and methods to improve decision-makings in organizations by using computer-based support systems [10]. BI refers to technologies, applications, concepts, and techniques used for the collection, integration, and demonstration of business information in order to make better decisions. In general, the purpose is to help organizations improve performance and enhance competitive advantage in the market [7]. Based on a brief review of the available literature, the enterprise intelligence can be classified in three approaches, namely, managerial, technical, and system-enabler [15]. The managerial approach defines BI as a process in which data collected from internal and external sources are integrated in order to generate information relevant to the decision-making process. It has also been reported in several studies, among which [16, 17] can be cited. However, the technical approach considers BI as a set of tools, algorithms, and technologies that support the above-mentioned process and its implementation. Further, the third approach proposed in the empowerment of enterprise systems focuses on the characteristics of BI as effective factors that may increase its information processing capabilities [15].

In addition to broad research at BI, some efforts have been made to deal with the business intelligence performance assessment. The accuracy of content, flexibility, ease of operation, on-time response, consistency and integration of the output, its reliability, and system security are the most common criteria for the evaluation of information systems [18, 19]. Using MADM techniques and network analysis, [3] developed a performance assessment model. The authors showed the necessity of measurement of BI effectiveness and determined a set of nine critical factors, including response time of system, its security, accuracy of the output, implementing the consultants' recommendations, support from top management and users, its conformity to requirements, its support of organizational efficiency, and support of decision-makings in the organization. Ghazanfari et al. [15] designed an assessment tool of BI for enterprise systems, regarding the considerable value of BI in empowering organizational systems. Through a comprehensive review on the literature, the authors identified 34 criteria in evaluating the enterprise-level BI, presented in the table below. Also, [5] proposed a new assessment model of BI for

Table 9.1 Evaluation criteria of BI for enterprise systems

Code	Criterion title	Code	Criterion title
C1	Group sorting tools and methodology (groupware)	C18	Alarms and warnings
C2	Group decision-making	C19	Dashboard/recommender
C3	Flexible models	C20	Combination of experiments
C4	Problem clustering	C21	Situation awareness modeling
C5	Optimization technique	C22	Environmental awareness
C6	Learning technique	C23	Fuzzy decision-making
C7	Import data from other systems	C24	OLAP
C8	Export reports to other systems	C25	Data mining techniques
C9	Simulation models	C26	Data warehouses
C10	Risk simulation	C27	Web channel
C11	Financial analyses tools	C28	Mobile channel
C12	Visual graphs	C29	E-mail channel
C13	Summarization	C30	Intelligent agent
C14	Evolutionary prototyping model	C31	Multi-agent
C15	Dynamic model prototyping	C32	MCDM tools
C16	Backward and forward reasoning	C33	Stakeholders' satisfaction
C17	Knowledge reasoning	C34	Reliability and accuracy of analysis

Fig. 9.1 Schematic diagram of research design

enterprise systems using fuzzy TOPSIS method. Because of the comprehensiveness of the criteria defined by [15], these criteria are derived and used to achieve the purpose of this study. Table 9.1 shows the criteria.

9.3 Methodology

The purpose of this study is to evaluate the level of BI for enterprise systems. To this end, through a review on previous studies, a set of major criteria were first identified for the BI assessment. In fact, the assessment was based on 34 criteria. Given the variety of criteria, the weighting process was employed by using the linguistic variables and expert panels. Further, a number of five expert systems were defined by the expert opinions and examined through an interval-valued intuitive fuzzy ARAS method. Figure 9.1 shows the research process.

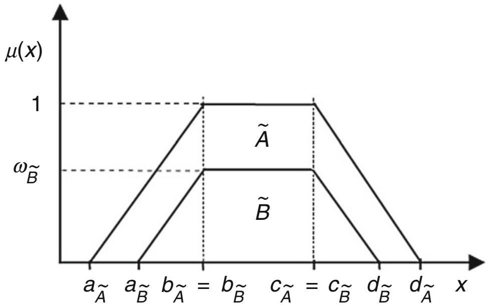


Fig. 9.2 Generalized fuzzy number

9.3.1 Generalized Fuzzy Numbers

A generalized fuzzy number $\tilde{A}$ is defined as (9.1),

$$\tilde{A} = (a, b, c, d; \omega),\ 0 \leq a \leq b \leq c \leq d \leq 1,\ 0 \leq \omega \leq 1 \tag{9.1}$$

It is a fuzzy subset of the real line R with the membership function $(\mu_{\tilde{A}})$ which has the following features [20]:

- $\mu_{\tilde{A}}$ is a continuous mapping from R to the closed interval [0, 1ω].
- $\forall x \in (-\infty, a] \rightarrow \mu_{\tilde{A}}(x) = 0$
- $\mu_{\tilde{A}}(x)$ is strictly increasing on [a, b].
- $\mu_{\tilde{A}}(x) = \omega$ for all $x \in [b, c]$, where ω is a constant on [0, 1], $0 \leq \omega \leq 1$.
- $\mu_{\tilde{A}}(x)$ is strictly decreasing on [c, d].
- $\mu_{\tilde{A}}(x) = 0$ for all $x \in [d, +\infty]$.

If $\mu_{\tilde{A}}$ is linear on the intervals [a, b] and [c, d], then a generalized fuzzy number is called a generalized trapezoidal fuzzy number. Figure 9.2 shows a relationship between the generalized fuzzy number, $\tilde{B}$, and the normalized trapezoidal fuzzy number, $\tilde{A}$.

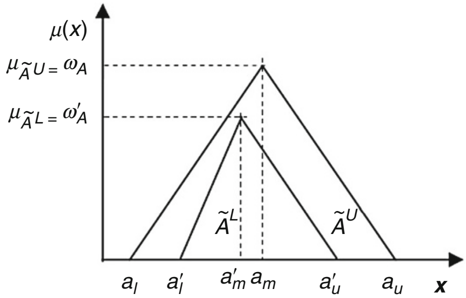
As seen from Fig. 9.2, the normalized trapezoidal fuzzy numbers demonstrate certain cases of generalized fuzzy numbers, where $\omega = 1$. Also, if $b = c$, then the trapezoidal fuzzy number becomes a triangular fuzzy number.

9.3.2 Interval-Valued Fuzzy Numbers

The interval-valued fuzzy numbers are special forms of generalized fuzzy numbers. Similar to generalized fuzzy numbers, these numbers can find a trapezoidal shape. Moreover, interval-valued triangular fuzzy numbers have a triangular shape. Figure 9.3 shows a graphical representation of an interval-valued triangular fuzzy number.

An interval-valued triangular fuzzy number can be defined as (9.2) [21]:

Fig. 9.3 Interval-valued triangular fuzzy number



$$\tilde{A} = \left[\tilde{A}^L, \tilde{A}^U\right] = \left[\left(a'_l, a'_m, a'_u; \omega'_A\right), (a_l, a_m, a_u; \omega_A)\right] \tag{9.2}$$

where $\tilde{A}^L$ and $\tilde{A}^U$ are the lower and upper triangular fuzzy numbers, $\tilde{A}^L \subset \tilde{A}^U$ and $\mu_{\tilde{A}}(x)$ are their membership functions. However, $\mu_{\tilde{A}}{}^L(x) = \omega'_A$ and $\mu_{\tilde{A}}{}^U(x) = \omega_A$ denote the lower and upper membership functions.

Suppose $\tilde{A} = \left[\tilde{A}^L, \tilde{A}^U\right]$ and $\tilde{B} = \left[\tilde{B}^L, \tilde{B}^U\right]$ are two interval-valued triangular fuzzy numbers. Then, the basic arithmetic operations on these fuzzy numbers can be represented as (9.3)–(9.6):

$$\tilde{A} + \tilde{B} = \left[\left(a'_l + b'_l, a'_m + b'_m, a'_u + b'_u; \min\left(\omega'_A, \omega'_B\right)\right), (a_l + b_l, a_m + b_m, a_u + b_u; \min(\omega_A, \omega_B))\right] \tag{9.3}$$

$$\tilde{A} - \tilde{B} = \left[\left(a'_l - b'_u, a'_m - b'_m, a'_u - b'_l; \min\left(\omega'_A, \omega'_B\right)\right), (a_l - b_u, a_m - b_m, a_u - b_l; \min(\omega_A, \omega_B))\right] \tag{9.4}$$

$$\tilde{A} \times \tilde{B} = \left[\left(a'_l \times b'_l, a'_m \times b'_m, a'_u \times b'_u; \min\left(\omega'_A, \omega'_B\right)\right), (a_l \times b_l, a_m \times b_m, a_u \times b_u; \min(\omega_A, \omega_B))\right] \tag{9.5}$$

$$\tilde{A} \div \tilde{B} = \left[\left(a'_l \div b'_u, a'_m \div b'_m, a'_u \div b'_l; \min\left(\omega'_A, \omega'_B\right)\right), (a_l \div b_u, a_m \div b_m, a_u \div b_l; \min(\omega_A, \omega_B))\right] \tag{9.6}$$

Figure 9.4 shows a certain case of generalized interval-valued fuzzy numbers, normalized with the same mode $\left(a'_m = a_m\right)$, and it can be represented as (9.7)

$$\tilde{A} = \left[\tilde{A}^L, \tilde{A}^U\right] = \left[\left(a_l, a'_l\right), a_m, \left(a'_u, a_u\right)\right] \tag{9.7}$$

Suppose $\tilde{A} = \left[\tilde{A}^L, \tilde{A}^U\right] = \left[\left(a_l, a'_l\right), a_m, \left(a'_u, a_u\right)\right]$ and $\tilde{B} = \left[\tilde{B}^L, \tilde{B}^U\right] = \left[\left(b_l, b'_l\right), b_m, \left(b'_u, b_u\right)\right]$ denote two normalized interval-valued triangular fuzzy numbers with the same mode. Then, the basic arithmetic operations on these fuzzy numbers can be defined as (9.8)–(9.11) [22]:

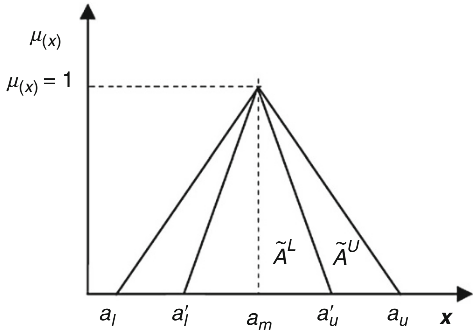


Fig. 9.4 Normalized interval-valued triangular fuzzy number with the same mode

$$\tilde{A} + \tilde{B} = \left[\left(a_l + b_l, a_l' + b_l'\right), a_m + b_m, \left(a_u' + b_u', a_u + b_u\right)\right] \tag{9.8}$$

$$\tilde{A} - \tilde{B} = \left[\left(a_l - b_u, a_l' - b_u'\right), a_m - b_m, \left(a_u' - b_l', a_u - b_l\right)\right] \tag{9.9}$$

$$\tilde{A} \times \tilde{B} = \left[\left(a_l \times b_l, a_l' \times b_l'\right), a_m \times b_m, \left(a_u' \times b_u', a_u \times b_u\right)\right] \tag{9.10}$$

$$\tilde{A} \div \tilde{B} = \left[\left(a_l \div b_u, a_l' \div b_u'\right), a_m \div b_m, \left(a_u' \div b_l', a_u \div b_l\right)\right] \tag{9.11}$$

In addition, the following unary operation defined on interval-valued triangular fuzzy numbers is of great importance. It is denoted as (9.12):

$$\frac{1}{k} \times \tilde{A} = \left[\left(\frac{1}{k} \times a_l, \frac{1}{k} \times a_l'\right), \frac{1}{k} \times a_m, \left(\frac{1}{k} \times a_u', \frac{1}{k} \times a_u\right)\right] \tag{9.12}$$

9.3.3 Linguistic Variables

The linguistic variables refer to variables whose values correspond to words or sentences in a natural or artificial language. A linguistic variable has a practical potential for dealing with many real-world decision-making problems, which are usually complex and relatively uncertain. A wide range of research studies have reported different linguistic variables with triangular fuzzy numbers [23–26]. Also, the literature provides linguistic variables based on the use of interval-valued fuzzy numbers. Wei and Chen [27], for example, developed a scale of nine level linguistic terms using interval-valued trapezoidal fuzzy numbers. Kuo and Liang [28], Kuo [29], and Ashtiani et al. [30] presented a seven level linguistic terms scale based on interval-valued triangular fuzzy numbers. Tables 9.2 and 9.3 show the linguistic variables for the weights of criteria and performance ratings, based on the use of triangular fuzzy numbers and interval-valued triangular fuzzy numbers [29–31].

Table 9.2 Linguistic variables for the weights of criteria

Linguistic variables	Triangular fuzzy number	Interval-valued triangular fuzzy number
Very low (VL)	(0.0, 0.0, 0.1)	[(0.00, 0.00), 0.0, (0.10, 0.15)]
Low (L)	(0.0, 0.1, 0.3)	[(0.00, 0.50), 0.1, (0.25, 0.35)]
Medium low (ML)	(0.1, 0.3, 0.5)	[(0.00, 0.15), 0.3, (0.45, 0.55)]
Medium (M)	(0.3, 0.5, 0.7)	[(0.25, 0.35), 0.5, (0.65, 0.75)]
Medium high (MH)	(0.5, 0.7, 0.9)	[(0.45, 0.55), 0.7, (0.80, 0.95)]
High (H)	(0.7, 0.7, 1.0)	[(0.55, 0.75), 0.9, (0.95, 1.00)]
Very high (VH)	(0.9, 1.0, 1.0)	[(0.85, 0.95), 1.0, (1.00, 1.00)]

Table 9.3 Linguistic variables for the performance ratings

Linguistic variables	Triangular fuzzy number	Interval-valued triangular fuzzy number
Very poor (VP)	(0.0, 0.0, 0.1)	[(0.00, 0.00), 0.0, (0.10, 0.15)]
Poor (P)	(0.0, 0.1, 0.3)	[(0.00, 0.50), 0.1, (0.25, 0.35)]
Medium poor (MP)	(0.1, 0.3, 0.5)	[(0.00, 0.15), 0.3, (0.45, 0.55)]
Fair (F)	(0.3, 0.5, 0.7)	[(0.25, 0.35), 0.5, (0.65, 0.75)]
Medium good (MG)	(0.5, 0.7, 0.9)	[(0.45, 0.55), 0.7, (0.80, 0.95)]
Good (G)	(0.7, 0.7, 1.0)	[(0.55, 0.75), 0.9, (0.95, 1.00)]
Very good (VG)	(0.9, 1.0, 1.0)	[(0.85, 0.95), 1.0, (1.00, 1.00)]

Since interval-valued fuzzy numbers are more complex than ordinary fuzzy numbers, the transformation of the ordinary fuzzy numbers into the corresponding interval-valued fuzzy numbers can raise some advantages. To transform their weights and performance ratings, the following equations are given:

$$l = \min_k \left(l^k\right) \tag{9.13}$$

$$l' = \left(\prod_{k=1}^{K} l^k\right)^{\frac{1}{K}} \tag{9.14}$$

$$m = \left(\prod_{k=1}^{K} m^k\right)^{\frac{1}{K}} \tag{9.15}$$

$$u' = \left(\prod_{k=1}^{K} u^k\right)^{\frac{1}{K}} \tag{9.16}$$

$$u = \max_k \left(u^k\right) \tag{9.17}$$

$\tilde{x} = [(l, l'), m, (u', u)]$ is the corresponding interval-valued triangular fuzzy number, while $\tilde{x}^k = \left(l^k, m^k, u^k\right)$ is the triangular fuzzy number obtained on the basis of opinion of kth decision-maker. The parameters l and u denote the smallest and the greatest performance ratings among all stakeholders, respectively, and they reflect the extreme attitudes provided by the experts. Unlike these parameters, other parameters of the interval-valued triangular fuzzy number reflect the expert opinions much more effectively. The reason is that these numbers are obtained as the geometric mean of attitudes from all experts.

9.3.4 Defuzzification of Interval-Valued Triangular Fuzzy Numbers

Since the results of arithmetic operations will be fuzzy numbers, they can be transformed into non-fuzzy numbers in order to rank and compare alternatives. Different procedures have been proposed for ranking fuzzy numbers and for their defuzzification, but these procedures concern mainly the trapezoidal or triangular fuzzy numbers. By small changes, however, the same procedures can be used for the defuzzification of interval-valued triangular fuzzy numbers. Equations (9.18) and (9.19) are two general defuzzification equations for triangular fuzzy numbers:

$$gm\left(\tilde{A}\right) = \frac{1}{2}[(1-\lambda)l + m + \lambda u] \tag{9.18}$$

$$gm\left(\tilde{A}\right) = \frac{1 + m + u}{3} \tag{9.19}$$

Moreover, (9.20) and (9.21) are proposed for defuzzification of interval-valued triangular fuzzy numbers:

$$gm\left(\tilde{B}\right) = \frac{l + l' + m + u' + u}{5} \tag{9.20}$$

$$gm\left(\tilde{B}\right) = \frac{(1-\lambda)l + \lambda l' + m + \lambda u' + (1-\lambda)u}{5} \tag{9.21}$$

where $\tilde{A}$ represents ordinary triangular fuzzy numbers, whereas $\tilde{B}$ presents interval-valued fuzzy numbers. λ is a coefficient on [0, 1].

Equation (9.20) is a simple extension of (9.19), providing an effective way for defuzzification of known interval-valued fuzzy numbers, represented as the Best Non-fuzzy Performance (BNP). In contrast, (9.20) is relatively more complex, but it has some advantages. For instance, varying the coefficient λ makes a greater importance to the parameters l' and u' against l and u, and vice versa.

9.3.5 Additive Ratio Assessment (ARAS) Method

As a relatively new tool for multi criteria decision making (MCDM), the ARAS method has received significant interested recently, still based on the theory that complex phenomena of the world could be accurately perceived trough a simple relative comparisons [32–34]. The ARAS method uses the concept of optimality degree to find a ranking. It is the sum of normalized weighted values of the criteria with respect to each alternative divided by the sum of normalized weighted values of the best alternative.

Step 1 First, a decision matrix is assembled as $\times n$, where m denotes alternatives and n denotes criteria.

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix};\ i = \overline{0, m};\ j = \overline{1, n} \tag{9.22}$$

x_{ij} is the performance measure of the ith alternative on the jth criterion. Also, x_{0j} shows the optimum value for the jth criterion. If the optimum value of the variable j is undetermined, then it can be determined as follows:

$$\begin{aligned} &\text{when } \max_i x_{ij} \text{ is optimal}, x_{0j} = \max_i x_{ij} \\ &\text{when } \min_i x^*_{ij} \text{ is optimal}, x_{0j} = \min_i x^*_{ij} \end{aligned} \tag{9.23}$$

In general, the evaluation values of alternatives with respect to criteria (x_{ij}) and the weights for each criterion (w_j) are given as the inputs in the decision matrix. Note that each criterion reflects its certain dimensions; therefore, a comparative analysis and preventing potential consequences from different dimensions require derive dimensionless quantities. To do this, the weighted values are simply divided by optimum obtained as (9.23). Numerous methods are available for deriving useful dimensionless values, which will be described below. Through normalization, the values of an original decision matrix are converted into the values on [0, 1] or on [0; ∞].

Step 2 The primary inputs are normalized for all criteria, represented by $\bar{x}_{ij}$ and formed the matrix elements.

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix};\ i = \overline{0, m};\ j = \overline{1, n} \tag{9.24}$$

Since there are benefit-type and cost-type criteria, the normalization is processed positively or negatively by using (9.25) and (9.26), respectively.

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{9.25}$$

$$x_{ij} = \frac{1}{x_{ij}^{*}} \bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{9.26}$$

The achievement of dimensionless quantities provides a framework for comparing each criterion against all others.

Step 3 Here, the weighted normalized decision matrix, $\hat{X}$, is calculated by applying the weight values on the normalized decision matrix $\bar{X}$.The weights are determined by expert panels and should meet the following requirements:

$$< w_j < 1, \sum_{j=1}^{n} w_j = 1$$

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \dots & \hat{x}_{0j} & \dots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \dots & \hat{x}_{ij} & \dots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \dots & \hat{x}_{mj} & \dots & \hat{x}_{mn} \end{bmatrix}; \ i = \overline{0, m}; \ j = \overline{1, n} \tag{9.27}$$

$$\hat{x}_{ij} = \bar{x}_{ij} \times w_j; \ i = \overline{0, m} \tag{9.28}$$

Again, w_j denotes the weight value for the jth criterion and $\bar{x}_{ij}$ represents the normalized value for the ith alternative. Therefore, the value of an optimal function can be calculated as follows:

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}; \ i = \overline{0, m} \tag{9.29}$$

According to the logic of ARAS, the best alternative is the only one with the greatest value for an optimal function. Clearly, the worst alternative obtains the value of minimum for the optimal function. To put it differently, the alternative ranking is determined based on the value of S_i.

The degree of utility can be measured by comparing each alternative against the best/optimal one with the best value, represented by S_0. The degree of utility, K_i, of the alternative A_i follows (9.30):

$$K_i = \frac{S_i}{S_0};\ i = \overline{0, m} \tag{9.30}$$

where S_0 and S_i are derived from (9.29). Clearly, K_i places on the interval [0, 1]. And, its value is used for ranking all alternatives.

9.3.6 An Extension of ARAS Method Based on Interval-Valued Triangular Fuzzy Numbers

In many practical situations, there exists information which is incomplete and uncertain, and decision-makers cannot easily express their judgments on the candidates with exact and crisp values. Therefore, interval-valued fuzzy sets provide generally more adequate description to model real-life decision problems than real numbers [35]. This allows us to achieve a better imagination from ambiguity and uncertainty related to the environment [36]. Considering uncertainty related to our case, we use interval-valued fuzzy ARAS in this article.

Step 1: Determine the Optimal Performance Rating for Each Criterion
The first point to be considered is that the optimal performance rating for each criterion should be calculated as an interval-valued fuzzy number. Therefore, optimal interval-valued fuzzy performance ratings can be determined as follows:

$$\tilde{x}_{0j} = \left[\left(l_{0j}, l'_{0j}\right), m_{0j}, \left(u'_{0j}, u_{0j}\right)\right] \tag{9.31}$$

where $\tilde{x}_{0j}$ represents the optimal interval-valued fuzzy performance rating of the jth criterion. Also, other criteria are defined as follows:

$$l_{0j} = \begin{cases} \max\limits_i l_{ij};\ j \in \Omega_{\max} \\ \min\limits_i l_{ij};\ j \in \Omega_{\min} \end{cases} \tag{9.32}$$

$$l'_{0j} = \begin{cases} \max\limits_i l'_{ij};\ j \in \Omega_{\max} \\ \min\limits_i l'_{ij};\ j \in \Omega_{\min} \end{cases} \tag{9.33}$$

$$m_{0j} = \begin{cases} \max\limits_i m_{ij};\ j \in \Omega_{\max} \\ \min\limits_i m_{ij};\ j \in \Omega_{\min} \end{cases} \tag{9.34}$$

$$u'_{0j} = \begin{cases} \max\limits_i u'_{ij};\ j \in \Omega_{\max} \\ \min\limits_i u'_{ij};\ j \in \Omega_{\min} \end{cases} \tag{9.35}$$

$$u_{0j} = \begin{cases} \max\limits_i u_{ij};\ j \in \Omega_{\max} \\ \min\limits_i u_{ij};\ j \in \Omega_{\min} \end{cases} \tag{9.36}$$

Step 2: Calculate the Normalized Decision Matrix

To enable the use of these interval-valued fuzzy numbers, the normalization process requires some modifications. So, (9.29) can be replaced by (9.37):

$$\tilde{r}_{ij} = \begin{cases} \left[\left(\frac{a_{ij}}{c_j^+}, \frac{a'_{ij}}{c_j^+}\right), \frac{b_{ij}}{c_j^+}, \left(\frac{c'_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right)\right];\ j \in \Omega_{\max} \\ \left[\left(\frac{\frac{1}{a_{ij}}}{a_j^-}, \frac{\frac{1}{a'_{ij}}}{a_j^-}\right), \frac{\frac{1}{b_{ij}}}{a_j^-}, \left(\frac{\frac{1}{c'_{ij}}}{a_j^-}, \frac{\frac{1}{c_{ij}}}{a_j^-}\right)\right];\ j \in \Omega_{\min} \end{cases} \tag{9.37}$$

Here, $\tilde{r}_{ij}$ is the optimal interval-valued fuzzy performance rating for the ith alternative on the jth criterion. Further,

$a_j^- = \sum_{i=0}^{m} \frac{1}{a_{ij}},\ c_j^+ = \sum_{i=0}^{m} c_{ij},\ i = 0, 1, \ldots, m$

Step 3: Calculate the Normalized Weighted Interval-Valued Decision Matrix

This is principally similar to the third step in the original ARAS method. The difference is that fuzzy numbers are to be now multiplied by using the multiplication operation on interval-valued triangular fuzzy numbers. Therefore, this can be expressed as follows:

$$\tilde{v}_{ij} = \tilde{w}_j \cdot \tilde{r}_{ij} \tag{9.38}$$

where $\tilde{v}_{ij}$ is the normalized weighted interval-valued fuzzy performance rating for the ith alternative on the jth criterion.

Step 4: Compute the Overall Interval-Valued Fuzzy Performance Ratings

This step can be expressed using (9.39):

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{v}_{ij} \tag{9.39}$$

where $\tilde{S}_i$ is the overall interval-valued fuzzy performance rating for the ith alternative.

Step 5: Measure the Degree of Utility for Each Alternative

Since the result obtained from the previous step is provided as an interval-valued fuzzy numbers, the calculation process is often more complex with the overall degree of utility. Obviously, it should be transformed into a non-fuzzy number. The degree of utility can be calculated as follows:

$$\tilde{Q}_i = \frac{\tilde{S}_i}{\tilde{S}_0} \tag{9.40}$$

Again, as the products of (9.40) are still interval-valued fuzzy numbers, these are typically needed to be defuzzified. The defuzzification process must be initiated prior of determining the degree of utility. There are a wide range of defuzzification methods with a variety of impacts on resultant outputs. Therefore, it is important how to choose an appropriate defuzzification technique.

Step 6: Rank Alternatives and Select the Most Efficient One
This step follows the similar process as the original ARAS method.

9.4 Results and Discussion

In order to achieve the purpose for ranking enterprise systems in business environments, five alternatives were defined and 34 criteria were evaluated accordingly, as represented in Table 9.1. Then, each criterion was weighted through the expert panel discussions based on the linguistic variables in Table 9.2. Further, the evaluation process was performed for each alternative on all criteria using the linguistic variables in Table 9.3. Table 9.4 provides the decision-making table obtained from the expert opinions.

According to Tables 9.2 and 9.3, the weighting values of triangular fuzzy numbers are usually converted into interval-valued fuzzy numbers. Table 9.5 represents the weights for all criteria.

As found from the column before the last, the weights previously displayed by interval-valued fuzzy numbers are converted to non-fuzzy values by using (9.21), where $\lambda = 0.5$. Finally, in order to normalize these defuzzified weights, the non-fuzzy weighting values for one criterion are first divided by the total value of non-fuzzy weights of all criteria, and so the corresponding defuzzified value is achieved for that criterion (again, according to the column before the last in Table 9.5). Also, Fig. 9.5 shows the comparative results for weighting values of effective criteria in order to select best smart systems with respect to BI.

As seen, the most important assessment criteria defined by expert panels include visual graph display, dashboard/recommender design, capable of data storage, meeting stakeholder needs, and the possibility for detailed realistic analysis. We can use Eq. (9.36) to determine the reference point (X_0) (Table 9.6).

Then, (9.37) is applied for decision matrix normalization, which is represented as Table 9.7. However, the weighting values are multiplied by the values in the normalized decision table using (9.5). Table 9.8 shows the result of weighted normalized decision table. For each alternative, the performance ratings and utility

Table 9.4 Decision-making table based on expert panels

Code	Weights	ES1	ES2	ES3	ES4	ES5	Code	Weights	ES1	ES2	ES3	ES4	ES5
C1	MH	VP	P	F	MG	MG	C18	H	MG	VG	MG	MG	MG
C2	H	MP	F	MG	G	MG	C19	VH	VG	VG	MG	VG	MG
C3	MH	F	P	MP	F	P	C20	H	VP	MP	F	VP	P
C4	M	MP	VP	P	F	MP	C21	L	P	VP	F	MP	F
C5	M	MG	VP	P	F	MP	C22	M	VP	F	F	P	VP
C6	M	F	VP	P	G	VP	C23	M	VP	F	F	MG	P
C7	H	G	VG	MG	G	G	C24	H	MG	F	F	VG	F
C8	H	MG	G	MG	VG	MG	C25	H	VG	MG	G	G	G
C9	MH	VG	MG	F	VP	MG	C26	VH	VG	G	MG	G	MG
C10	M	F	MP	F	F	MG	C27	MH	VG	G	VG	VG	G
C11	L	F	V	P	F	MG	C28	M	F	MG	F	F	VG
C12	VH	VG	VG	MG	G	MG	C29	M	VP	P	F	MG	F
C13	H	F	MG	F	MG	VG	C30	H	VP	MG	MP	P	F
C14	L	G	VP	MP	P	VP	C31	H	VP	P	F	VP	F
C15	M	MP	VP	P	MP	VP	C32	H	MG	P	MP	F	VG
C16	MH	VP	VP	F	F	VP	C33	VH	F	F	P	MG	F
C17	MH	F	P	F	MG	VP	C34	VH	VG	P	F	F	MG

Table 9.5 Weighting values as interval-valued fuzzy numbers

Code	Interval-valued fuzzy weights	BNP	Non-fuzzy normal weights	Code	Interval-valued fuzzy weights	BNP	Non-fuzzy normal weights
C1	([0.45, 0.55], 0.7, [0.8, 0.95])	0.6917	0.030	C18	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036
C2	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036	C19	([0.85, 0.95], 1.0, [1.0, 1.0])	0.9667	0.042
C3	([0.45, 0.55], 0.7, [0.8, 0.95])	0.6917	0.030	C20	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036
C4	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022	C21	([0, 0.05], 0.1, [0.25, 0.35])	0.1417	0.006
C5	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022	C22	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022
C6	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022	C23	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022
C7	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036	C24	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036
C8	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036	C25	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036
C9	([0.45, 0.55], 0.7, [0.8, 0.95])	0.6917	0.030	C26	([0.85, 0.95],1.0, [1.0, 1.0])	0.9667	0.042
C10	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022	C27	([0.45, 0.55], 0.7, [0.8, 0.95])	0.6917	0.030
C11	([0, 0.05], 0.1, [0.25, 0.35])	0.1417	0.006	C28	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022
C12	([0.85, 0.95], 1.0, [1.0, 1.0])	0.9667	0.042	C29	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022
C13	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036	C30	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036
C14	([0, 0.05], 0.1, [0.25, 0.35])	0.1417	0.006	C31	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036
C15	([0.25, 0.35], 0.5, [0.65, 0.75])	0.5	0.022	C32	([0.55, 0.75], 0.9, [0.95, 1.0])	0.8417	0.036
C16	([0.45, 0.55], 0.7, [0.8, 0.95])	0.6917	0.030	C33	([0.85, 0.95],1.0, [1.0, 1.0])	0.9667	0.042
C17	([0.45, 0.55], 0.7, [0.8, 0.95])	0.6917	0.030	C34	([0.85, 0.95],1.0, [1.0, 1.0])	0.9667	0.042

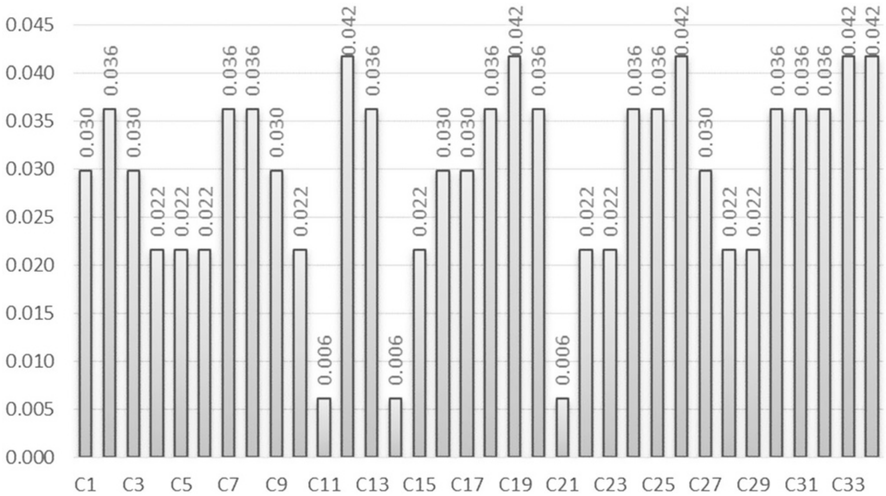


Fig. 9.5 Comparative results for effective weighting values against enterprise-level BI

Table 9.6 Decision-making table based on expert panels

Code	Interval-valued fuzzy weights	Code	Interval-valued fuzzy weights
C1	([0.45, 0.55], 0.7, [0.8, 0.95])	C18	([0.85, 0.95], 1, [1])
C2	([0.55, 0.75], 0.9, [0.95, 1])	C19	([0.85, 0.95], 1, [1])
C3	([0.25, 0.35], 0.5, [0.65, 0.75])	C20	([0.25, 0.35], 0.5, [0.65, 0.75])
C4	([0.25, 0.35], 0.5, [0.65, 0.75])	C21	([0.25, 0.35], 0.5, [0.65, 0.75])
C5	([0.45, 0.55], 0.7, [0.8, 0.95])	C22	([0.25, 0.35], 0.5, [0.65, 0.75])
C6	([0.55, 0.75], 0.9, [0.95, 1])	C23	([0.45, 0.55], 0.7, [0.8, 0.95])
C7	([0.85, 0.95], 1, [1])	C24	([0.85, 0.95], 1, [1])
C8	([0.85, 0.95], 1, [1])	C25	([0.85, 0.95], 1, [1])
C9	([0.85, 0.95], 1, [1])	C26	([0.85, 0.95], 1, [1])
C10	([0.45, 0.55], 0.7, [0.8, 0.95])	C27	([0.85, 0.95], 1, [1])
C11	([0.45, 0.55], 0.7, [0.8, 0.95])	C28	([0.85, 0.95], 1, [1])
C12	([0.85, 0.95], 1, [1])	C29	([0.45, 0.55], 0.7, [0.8, 0.95])
C13	([0.85, 0.95], 1, [1])	C30	([0.45, 0.55], 0.7, [0.8, 0.95])
C14	([0.55, 0.75], 0.9, [0.95,1])	C31	([0.25, 0.35], 0.5, [0.65, 0.75])
C15	([0, 0.15], 0.3, [0.45, 0.55])	C32	([0.85, 0.95], 1, [1])
C16	([0.25, 0.35], 0.5, [0.65, 0.75])	C33	([0.45, 0.55], 0.7, [0.8, 0.95])
C17	([0.45, 0.55], 0.7, [0.8, 0.95])	C34	([0.85, 0.95], 1, [1])

degrees are calculated by using (9.39) and (9.40). Then, these numbers are defuzzified and ranked based on different values of λ. Table 9.9 represents the computational results.

It can be found that for different value of λ, the smart business system ES4 is the best alternative. Based on the comparative analysis, this alternative provides an outstanding performance on the criteria of groupware programs, group decision-

Table 9.7 Normalized decision table

Code	ES1	ES2	ES3	ES4	ES5
C1	([0, 0], 0, [0.02, 0.04])	([0, 0.01], 0.02, [0.06, 0.09])	([0.06, 0.09], 0.12, [0.16, 0.18])	([0.11, 0.13], 0.17, [0.2, 0.23])	([0.11, 0.13], 0.17, [0.2, 0.23])
C2	([0, 0.03], 0.06, [0.09, 0.11])	([0.05, 0.07], 0.1, [0.13, 0.14])	([0.09, 0.11], 0.13, [0.15, 0.18])	([0.11, 0.14], 0.17, [0.18, 0.19])	([0.09, 0.11], 0.13, [0.15, 0.18])
C3	([0.07, 0.1], 0.14, [0.19, 0.21])	([0, 0.01], 0.03, [0.07, 0.1])	([0, 0.04], 0.09, [0.13, 0.16])	([0.07, 0.1], 0.14, [0.19, 0.21])	([0, 0.01], 0.03, [0.07, 0.1])
C4	([0, 0.05], 0.1, [0.15, 0.18])	([0, 0], 0, [0.03, 0.05])	([0, 0.02], 0.03, [0.08, 0.11])	([0.08, 0.11], 0.16, [0.21, 0.24])	([0, 0.05], 0.1, [0.15, 0.18])
C5	([0.12, 0.15], 0.19, [0.22, 0.26])	([0, 0], 0, [0.03, 0.04])	([0, 0.01], 0.03, [0.07, 0.09])	([0.07, 0.09], 0.14, [0.18, 0.2])	([0, 0.04], 0.08, [0.12, 0.15])
C6	([0.07, 0.1], 0.15, [0.19, 0.22])	([0, 0], 0, [0.03, 0.04])	([0, 0.01], 0.03, [0.07, 0.1])	([0.16, 0.22], 0.26, [0.28, 0.29])	([0, 0], 0, [0.03, 0.04])
C7	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.08, 0.09], 0.12, [0.13, 0.16])	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.09, 0.13], 0.15, [0.16, 0.17])
C8	([0.08, 0.09], 0.12, [0.14, 0.16])	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])	([0.15, 0.16], 0.17, [0.17, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])
C9	([0.18, 0.2], 0.21, [0.21, 0.21])	([0.09, 0.11], 0.15, [0.17, 0.2])	([0.05, 0.07], 0.1, [0.14, 0.16])	([0, 0], 0, [0.02, 0.03])	([0.09, 0.11], 0.15, [0.17, 0.2])
C10	([0.05, 0.07], 0.11, [0.14, 0.16])	([0, 0.03], 0.06, [0.1, 0.12])	([0.05, 0.07], 0.11, [0.14, 0.16])	([0.05, 0.07], 0.11, [0.14, 0.16])	([0.1, 0.12], 0.15, [0.17, 0.2])
C11	([0.07, 0.09], 0.13, [0.17, 0.2])	([0, 0], 0, [0, 0])	([0, 0.01], 0.03, [0.07, 0.09])	([0.07, 0.09], 0.13, [0.17, 0.2])	([0.12, 0.15], 0.19, [0.21, 0.25])
C12	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])
C13	([0.05, 0.06], 0.09, [0.12, 0.14])	([0.08, 0.1], 0.13, [0.15, 0.18])	([0.05, 0.06], 0.09, [0.12, 0.14])	([0.08, 0.1], 0.13, [0.15, 0.18])	([0.16, 0.18], 0.19, [0.19, 0.19])
C14	([0.17, 0.23], 0.28, [0.3, 0.31])	([0, 0], 0, [0.03, 0.05])	([0, 0.05], 0.09, [0.14, 0.17])	([0, 0.02], 0.03, [0.08, 0.11])	([0, 0], 0, [0.03, 0.05])
C15	([0, 0.07], 0.13, [0.2, 0.24])	([0, 0], 0, [0.04, 0.07])	([0, 0.02], 0.04, [0.11, 0.15])	([0, 0.07], 0.13, [0.2, 0.24])	([0, 0], 0, [0.04, 0.07])
C16	([0, 0], 0, [0.04, 0.06])	([0, 0], 0, [0.04, 0.06])	([0.09, 0.13], 0.19, [0.24, 0.28])	([0.09, 0.13], 0.19, [0.24, 0.28])	([0, 0], 0, [0.04, 0.06])
C17	([0.06, 0.09], 0.13, [0.17, 0.19])	([0, 0.01], 0.03, [0.06, 0.09])	([0.06, 0.09], 0.13, [0.17, 0.19])	([0.12, 0.14], 0.18, [0.21, 0.24])	([0, 0], 0, [0.03, 0.04])
C18	([0.08, 0.09], 0.12, [0.14, 0.16])	([0.15, 0.16], 0.17, [0.17, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])	([0.08, 0.09], 0.12, [0.14, 0.16])	([0.08, 0.09], 0.12, [0.14, 0.16])
C19	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])
C20	([0, 0], 0, [0.04, 0.06])	([0, 0.06], 0.11, [0.17, 0.2])	([0.09, 0.13], 0.19, [0.24, 0.28])	([0, 0], 0, [0.04, 0.06])	([0, 0.02], 0.04, [0.09, 0.13])
C21	([0, 0.02], 0.03, [0.08, 0.11])	([0, 0], 0, [0.03, 0.05])	([0.08, 0.11], 0.15, [0.2, 0.23])	([0, 0.05], 0.09, [0.14, 0.17])	([0.08, 0.11], 0.15, [0.2, 0.23])
C22	([0, 0], 0, [0.03, 0.05])	([0.09, 0.12], 0.17, [0.22, 0.26])	([0.09, 0.12], 0.17, [0.22, 0.26])	([0, 0.02], 0.03, [0.09, 0.12])	([0, 0], 0, [0.03, 0.05])
C23	([0, 0], 0, [0.03, 0.04])	([0.06, 0.09], 0.13, [0.17, 0.19])	([0.06, 0.09], 0.13, [0.17, 0.19])	([0.12, 0.14], 0.18, [0.21, 0.24])	([0, 0.01], 0.03, [0.06, 0.09])
C24	([0.09, 0.11], 0.13, [0.15, 0.18])	([0.05, 0.07], 0.1, [0.13, 0.14])	([0.05, 0.07], 0.1, [0.13, 0.14])	([0.16, 0.18], 0.19, [0.19, 0.19])	([0.05, 0.07], 0.1, [0.13, 0.14])
C25	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.08, 0.09], 0.12, [0.13, 0.16])	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.09, 0.13], 0.15, [0.16, 0.17])
C26	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.08, 0.09], 0.12, [0.14, 0.16])
C27	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.09, 0.13], 0.15, [0.16, 0.17])	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.14, 0.16], 0.17, [0.17, 0.17])	([0.09, 0.13], 0.15, [0.16, 0.17])
C28	([0.05, 0.07], 0.1, [0.13, 0.14])	([0.09, 0.11], 0.13, [0.15, 0.18])	([0.05, 0.07], 0.1, [0.13, 0.14])	([0.05, 0.07], 0.1, [0.13, 0.14])	([0.16, 0.18], 0.19, [0.19, 0.19])
C29	([0, 0], 0, [0.03, 0.04])	([0, 0.01], 0.03, [0.06, 0.09])	([0.06, 0.09], 0.13, [0.17, 0.19])	([0.12, 0.14], 0.18, [0.21, 0.24])	([0.06, 0.09], 0.13, [0.17, 0.19])
C30	([0, 0], 0, [0.03, 0.04])	([0.12, 0.15], 0.19, [0.22, 0.26])	([0, 0.04], 0.08, [0.12, 0.15])	([0, 0.01], 0.03, [0.07, 0.09])	([0.07, 0.09], 0.14, [0.18, 0.2])
C31	([0, 0], 0, [0.03, 0.05])	([0, 0.02], 0.03, [0.09, 0.12])	([0.09, 0.12], 0.17, [0.22, 0.26])	([0, 0], 0, [0.03, 0.05])	([0.09, 0.12], 0.17, [0.22, 0.26])
C32	([0.1, 0.12], 0.15, [0.17, 0.21])	([0, 0.01], 0.02, [0.05, 0.08])	([0, 0.03], 0.07, [0.1, 0.12])	([0.05, 0.08], 0.11, [0.14, 0.16])	([0.18, 0.21], 0.22, [0.22, 0.22])
C33	([0.06, 0.08], 0.11, [0.14, 0.17])	([0.06, 0.08], 0.11, [0.14, 0.17])	([0, 0.01], 0.02, [0.06, 0.08])	([0.1, 0.12], 0.16, [0.18, 0.21])	([0.06, 0.08], 0.11, [0.14, 0.17])
C34	([0.18, 0.2], 0.21, [0.21, 0.21])	([0, 0.01], 0.02, [0.05, 0.07])	([0.05, 0.07], 0.1, [0.14, 0.16])	([0.05, 0.07], 0.1, [0.14, 0.16])	([0.09, 0.11], 0.15, [0.17, 0.2])

Table 9.8 Weighted normalized decision table

Code	ES1	ES2	ES3	ES4	ES5
C1	([0, 0], 0, [0.02, 0.03])	([0, 0.01], 0.02, [0.05, 0.08])	([0.03, 0.05], 0.09, [0.13, 0.17])	([0.05, 0.07], 0.12, [0.16, 0.22])	([0.05, 0.07], 0.12, [0.16, 0.22])
C2	([0, 0.02], 0.05, [0.08, 0.11])	([0.03, 0.05], 0.09, [0.12, 0.14])	([0.05, 0.08], 0.12, [0.15, 0.18])	([0.06, 0.11], 0.16, [0.17, 0.19])	([0.05, 0.08], 0.12, [0.15, 0.18])
C3	([0.03, 0.06], 0.1, [0.15, 0.2])	([0, 0.01], 0.02, [0.06, 0.1])	([0, 0.02], 0.06, [0.1, 0.15])	([0.03, 0.06], 0.1, [0.15, 0.2])	([0, 0.01], 0.02, [0.06, 0.1])
C4	([0, 0.02], 0.05, [0.09, 0.13])	([0, 0], 0, [0.02, 0.04])	([0, 0.01], 0.02, [0.05, 0.08])	([0.02, 0.04], 0.08, [0.14, 0.18])	([0, 0.02], 0.05, [0.09, 0.13])
C5	([0.03, 0.05], 0.09, [0.14, 0.19])	([0, 0], 0, [0.02, 0.03])	([0, 0], 0.01, [0.04, 0.07])	([0.02, 0.03], 0.07, [0.11, 0.15])	([0, 0.01], 0.04, [0.08, 0.11])
C6	([0.02, 0.04], 0.07, [0.12, 0.17])	([0, 0], 0, [0.02, 0.03])	([0, 0.01], 0.01, [0.05, 0.08])	([0.04, 0.08], 0.13, [0.18, 0.22])	([0, 0], 0, [0.02, 0.03])
C7	([0.05, 0.09], 0.14, [0.15, 0.17])	([0.08, 0.12], 0.15, [0.16, 0.17])	([0.04, 0.07], 0.11, [0.13, 0.16])	([0.05, 0.09], 0.14, [0.15, 0.17])	([0.05, 0.09], 0.14, [0.15, 0.17])
C8	([0.04, 0.07], 0.11, [0.13, 0.16])	([0.05, 0.1], 0.14, [0.15, 0.17])	([0.04, 0.07], 0.11, [0.13, 0.16])	([0.08, 0.12], 0.15, [0.16, 0.17])	([0.04, 0.07], 0.11, [0.13, 0.16])
C9	([0.08, 0.11], 0.15, [0.17, 0.2])	([0.04, 0.06], 0.1, [0.13, 0.19])	([0.02, 0.04], 0.07, [0.11, 0.15])	([0, 0], 0, [0.02, 0.03])	([0.04, 0.06], 0.1, [0.13, 0.19])
C10	([0.01, 0.03], 0.05, [0.09, 0.12])	([0, 0.01], 0.03, [0.06, 0.09])	([0.01, 0.03], 0.05, [0.09, 0.12])	([0.01, 0.03], 0.05, [0.09, 0.12])	([0.02, 0.04], 0.07, [0.11, 0.15])
C11	([0, 0], 0.01, [0.04, 0.07])	([0, 0], 0, [0, 0])	([0, 0], 0, [0.02, 0.03])	([0, 0], 0.01, [0.04, 0.07])	([0, 0.01], 0.02, [0.05, 0.09])
C12	([0.12, 0.15], 0.17, [0.17, 0.17])	([0.12, 0.15], 0.17, [0.17, 0.17])	([0.06, 0.09], 0.12, [0.14, 0.16])	([0.08, 0.12], 0.15, [0.16, 0.17])	([0.06, 0.09], 0.12, [0.14, 0.16])
C13	([0.03, 0.05], 0.08, [0.11, 0.14])	([0.05, 0.08], 0.12, [0.14, 0.18])	([0.03, 0.05], 0.08, [0.11, 0.14])	([0.05, 0.08], 0.12, [0.14, 0.18])	([0.09, 0.13], 0.17, [0.18, 0.19])
C14	([0, 0.01], 0.03, [0.07, 0.11])	([0, 0], 0, [0.01, 0.02])	([0, 0], 0.01, [0.04, 0.06])	([0, 0], 0, [0.02, 0.04])	([0, 0], 0, [0.01, 0.02])
C15	([0, 0.02], 0.07, [0.13, 0.18])	([0, 0], 0, [0.03, 0.05])	([0, 0.01], 0.02, [0.07, 0.11])	([0, 0.02], 0.07, [0.13, 0.18])	([0, 0], 0, [0.03, 0.05])
C16	([0, 0], 0, [0.03, 0.05])	([0, 0], 0, [0.03, 0.05])	([0.04, 0.07], 0.13, [0.19, 0.26])	([0.04, 0.07], 0.13, [0.19, 0.26])	([0, 0], 0, [0.03, 0.05])
C17	([0.03, 0.05], 0.09, [0.13, 0.18])	([0, 0.01], 0.02, [0.05, 0.09])	([0.03, 0.05], 0.09, [0.13, 0.18])	([0.05, 0.08], 0.13, [0.16, 0.23])	([0, 0], 0, [0.02, 0.04])
C18	([0.04, 0.07], 0.11, [0.13, 0.16])	([0.08, 0.12], 0.16, [0.16, 0.17])	([0.04, 0.07], 0.11, [0.13, 0.16])	([0.04, 0.07], 0.11, [0.13, 0.16])	([0.04, 0.07], 0.11, [0.13, 0.16])
C19	([0.12, 0.15], 0.17, [0.17, 0.17])	([0.12, 0.15], 0.17, [0.17, 0.17])	([0.06, 0.09], 0.12, [0.14, 0.16])	([0.12, 0.15], 0.17, [0.17, 0.17])	([0.06, 0.09], 0.12, [0.14, 0.16])
C20	([0, 0], 0, [0.04, 0.06])	([0, 0.04], 0.1, [0.16, 0.2])	([0.05, 0.1], 0.17, [0.23, 0.28])	([0, 0], 0, [0.04, 0.06])	([0, 0.01], 0.03, [0.09, 0.13])
C21	([0, 0], 0, [0.02, 0.04])	([0, 0], 0, [0.01, 0.02])	([0, 0.01], 0.02, [0.05, 0.08])	([0, 0], 0.01, [0.03, 0.06])	([0, 0.01], 0.02, [0.05, 0.08])
C22	([0, 0], 0, [0.02, 0.04])	([0.02, 0.04], 0.09, [0.15, 0.19])	([0.02, 0.04], 0.09, [0.15, 0.19])	([0, 0.01], 0.02, [0.06, 0.09])	([0, 0], 0, [0.02, 0.04])
C23	([0, 0], 0, [0.02, 0.03])	([0.02, 0.03], 0.06, [0.11, 0.14])	([0.02, 0.03], 0.06, [0.11, 0.14])	([0.03, 0.05], 0.09, [0.13, 0.18])	([0, 0], 0.01, [0.04, 0.07])
C24	([0.05, 0.08], 0.12, [0.15, 0.18])	([0.03, 0.05], 0.09, [0.12, 0.14])	([0.03, 0.05], 0.09, [0.12, 0.14])	([0.09, 0.14], 0.17, [0.18, 0.19])	([0.03, 0.05], 0.09, [0.12, 0.14])
C25	([0.08, 0.12], 0.15, [0.16, 0.17])	([0.04, 0.07], 0.11, [0.13, 0.16])	([0.05, 0.09], 0.14, [0.15, 0.17])	([0.05, 0.09], 0.14, [0.15, 0.17])	([0.05, 0.09], 0.14, [0.15, 0.17])
C26	([0.12, 0.15], 0.17, [0.17, 0.17])	([0.08, 0.12], 0.15, [0.16, 0.17])	([0.06, 0.09], 0.12, [0.14, 0.16])	([0.08, 0.12], 0.15, [0.16, 0.17])	([0.06, 0.09], 0.12, [0.14, 0.16])
C27	([0.06, 0.09], 0.12, [0.13, 0.16])	([0.04, 0.07], 0.11, [0.13, 0.16])	([0.06, 0.09], 0.12, [0.13, 0.16])	([0.06, 0.09], 0.12, [0.13, 0.16])	([0.04, 0.07], 0.11, [0.13, 0.16])
C28	([0.01, 0.02], 0.05, [0.08, 0.11])	([0.02, 0.04], 0.07, [0.1, 0.14])	([0.01, 0.02], 0.05, [0.08, 0.11])	([0.01, 0.02], 0.05, [0.08, 0.11])	([0.04, 0.06], 0.1, [0.13, 0.14])
C29	([0, 0], 0, [0.02, 0.03])	([0, 0], 0.01, [0.04, 0.07])	([0.02, 0.03], 0.06, [0.11, 0.14])	([0.03, 0.05], 0.09, [0.13, 0.18])	([0.02, 0.03], 0.06, [0.11, 0.14])
C30	([0, 0], 0, [0.03, 0.04])	([0.07, 0.11], 0.17, [0.21, 0.26])	([0, 0.03], 0.07, [0.12, 0.15])	([0, 0.01], 0.02, [0.06, 0.09])	([0.04, 0.07], 0.12, [0.17, 0.2])
C31	([0, 0], 0, [0.03, 0.05])	([0, 0.01], 0.03, [0.08, 0.12])	([0.05, 0.09], 0.16, [0.21, 0.26])	([0, 0], 0, [0.03, 0.05])	([0.05, 0.09], 0.16, [0.21, 0.26])
C32	([0.05, 0.09], 0.14, [0.17, 0.21])	([0, 0.01], 0.02, [0.05, 0.08])	([0, 0.02], 0.06, [0.09, 0.12])	([0.03, 0.06], 0.1, [0.13, 0.16])	([0.1, 0.15], 0.2, [0.21, 0.22])
C33	([0.05, 0.07], 0.11, [0.14, 0.17])	([0.05, 0.07], 0.11, [0.14, 0.17])	([0, 0.01], 0.02, [0.06, 0.08])	([0.09, 0.12], 0.16, [0.18, 0.21])	([0.05, 0.07], 0.11, [0.14, 0.17])
C34	([0.15, 0.19], 0.21, [0.21, 0.21])	([0, 0.01], 0.02, [0.05, 0.07])	([0.04, 0.07], 0.1, [0.14, 0.16])	([0.04, 0.07], 0.1, [0.14, 0.16])	([0.08, 0.11], 0.15, [0.17, 0.2])

Table 9.9 Final results of overall performance ratings, degrees of utility, and final ranking for different values of λ

		$\lambda = 0.5$			$\lambda = 0$			$\lambda = 1$		
	S	Sm	Q	Rank	Sm	Q	Rank	Sm	Q	Rank
X0	([1.98, 3.01], 4.28, [5.30, 6.37])	4.201	1	0	4.207	1	0	4.195	1	0
ES1	([1.18, 1.81], 2.60, [3.52, 4.37])	2.681	0.638	4	2.719	0.646	4	2.643	0.630	4
ES2	([0.93, 1.55], 2.31, [3.18, 4.01])	2.382	0.567	5	2.418	0.574	5	2.347	0.559	5
ES3	([0.88, 1.58], 2.65, [3.81, 4.95])	2.752	0.655	3	2.824	0.671	2	2.679	0.638	3
ES4	([1.26, 2.05], 3.10, [4.13, 5.16])	3.132	0.745	1	3.172	0.754	1	3.091	0.736	1
ES5	([1.07, 1.77], 2.70, [3.66, 4.64])	2.755	0.655	2	2.801	0.666	3	2.709	0.645	2

making tools, training techniques, data transfer capability, knowledge inference, supporting fuzzy concepts under ambiguity and uncertainty, real-time analytical processing, managing email channels, and achieving stakeholder satisfaction.

9.5 Conclusion and Recommendations

Business intelligence (BI) is among the fundamental components of information system resources as well as the essential requirements for an organization's success. The growing tendency to use smart devices in enterprise systems has increased the practical necessity of enterprise-level BI evaluation. The current study applied BI as the key requirement for enterprise systems. It evaluated 34 criteria derived from the literature review and also 5 alternatives as the levels of BI through the application of MCDM techniques. In this line, the study used different linguistics variables and an interval-valued intuitive fuzzy ARAS technique. The results revealed that the most important assessment criteria defined by expert panels included visual graph display, dashboard and recommender, capable of data storage, meeting stakeholder needs, and the possibility for detailed realistic analysis. When the values of criterion weights determined, the ARAS method proposed here was employed to evaluate and rank the enterprise systems under study.

The framework provided here can be utilized by organizations to make sound decisions regarding their levels of business intelligence. Also, the application of interval-valued intuitive fuzzy ARAS technique may result to solutions of increased accuracy under uncertainty, compared to the conventional fuzzy approach. Further studies are recommended to use different decision-making approaches and methods under uncertainty, so it would be possible to compare the current results with the findings from other major research studies.

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Chapter 10
Appropriate Renewable Energy Sources for Electricity Generation: A Multi-Attribute Decision-Making Approach

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10.1 Introduction

The high demand for energy consumption, growing use of natural resources, and causing environmental pollution are included among the most critical concerns in today's world [1]. For this reason, the selection of energy sources that provide the most benefit and the least damage and pollution for satisfying human needs has often been identified as a major challenge in many countries [2].

Energy planning covers one of the most important topics at the local, national, regional, and even global levels, which has been recently introduced in politics [3]. In the past, most decisions made for the selection of appropriate energy technologies relied on technological and economic models [4]. Nowadays, one of the most important issues of energy planning is to select suitable means for the production of energy. Some available alternatives include solar energy, wind power, marine energy, and so on [5–8]. However, other sources such as coal and natural gas are currently being used [6, 9]. Based on the literature, the importance of decision-making on energy alternatives through the use of multi-attribute decision-making (MADM) techniques has been expanded since 1995 [10].

Due to the increasing global importance of energy and development of studies conducted in the field of new energy sources, this paper focuses on the selection of appropriate technology for electricity generation. The preparation process of this study covers the following steps:

First, the existing literature and studies in renewable energy are reviewed, and the suitable attributes for decision-making are achieved as to select the best alternative. It provides the general framework for decision-making. This framework includes all

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four major aspects—that is, technological, economic, environmental, and social—and embeds 20 attributes. Then, all attributes are finalized by the experts, and the relevant table is evaluated. The alternatives surveyed in this study include wind power, solar energy, biomass, and hydroelectricity. Using the expert opinions and the correlation coefficient and standard deviation (CCSD) integrated method, the weight of each attribute is calculated. Ultimately, the complex proportional assessment (COPRAS) method is applied, to determine the priority of each alternative and, accordingly, the best is selected among these four alternatives.

10.2 Literature Review

Since the introduction of MADM methods into the realm of renewable energy, a variety of studies have been developed with different aims and objectives. To evaluate the future of energy systems in Germany, a new structure based on combinations of criteria was proposed by Keeney et al. [11]. Hämäläinen and Karjalainen dealt with weighting the evaluation criteria of Finland's energy policies, using an analytical hierarchy process (AHP) [12]. Through a MADM analysis, the external costs of power plants based on different energy sources were examined by Mirasgedis and Diakoulaki [13]. In Ref. [14], Mavrotas et al. proposed a multiple objective linear programming (MOLP) model for the electricity generation sector in Greece. Afgan and Carvalho described the evaluation criteria for appropriate energy systems in their study [15]. Haralambopoulos and Polatidis applied the PROMETHEE II method for the assessment of energy field projects [16]. Polatidis and Haralambopoulos developed a methodological framework using the MADM to assess the alternatives of renewable energy sources [17]. In Ref. [18], Topcu and Ulengin presented an integrated decision-making framework for selecting the appropriate electric energy source in Turkey. Cavallaro and Ciraolo developed a MADM-based method (NAIADE) to analyze the feasibility of installing wind energy turbines in Italy [19]. Using the MADM approaches, Begić and Afgan proposed an assessment tool for the selection of energy systems in Bosnia and Herzegovina [20]. Burton and Hubacek discussed the best energy alternatives through a comparative analysis of economic, environmental, and social costs [21]. Afgan et al. evaluated the natural gas utilization in energy sector [22]. Through an analytical network process (ANP) Ref. [23] focused on evaluating the energy sources for Turkish manufacturing industry. Patlitzianas implemented an information decision support system combined with the ELECTRE III method in the energy sector [24]. Kahraman et al. selected the best renewable energy alternative using fuzzy axiomatic design and fuzzy analytic hierarchy process [25]. Wang reviewed multi-criteria decision analysis aid in sustainable energy decision-making [26]. In Ref. [27], Kahraman and Kaya used a fuzzy AHP for the selection of proper energy alternatives in Turkey. The authors organized four main categories: namely, technological, environmental, socio-political, and economic, with 17 different sub-criteria. Wang et al. presented a framework for energy source selection in China. To select the proper alternative, this paper used six major categories of availability, infrastructure, price, safety, environmental impact, and social effects, and 17 sub-criteria [28]. Barry et al. [29] evaluated eight case studies in Africa for the selection of proper energy sources. Case studies were discussed from five points of view, including technological factors, spatial factors, economic and financial factors, availability, and freshness. Kaya and Kahraman applied a modified fuzzy TOPSIS approach for energy planning [30]. The attributes considered here are consisted of four technical, economic, social, and environmental categories, with 25 sub-criteria. Doukas provided a MADM-based framework for decision-making regarding energy systems, using six major categories [31]. For the evaluation of renewable energy sources for electricity generation in Yazd, Sadeghi et al. proposed a fuzzy MADM approach where the attributes included four categories of socio-political, economic, environmental, and technological factors, with 13 major sub-criteria [32]. Ahmad and Tahar used an AHP approach for the selection of proper renewable energy sources for generating electricity in Malaysia. In this study, 4 categories of technical, economic, social, and environmental aspects and 12 sub-criteria were organized [33]. Dat and Chou presented an evaluation model by a fuzzy hybrid MADM approach for selecting the appropriate renewable energy. The attributes used were divided into five main categories [2]. Kabak and Dağdeviren discussed prioritizing of renewable energy sources in Turkey [34]. The authors applied a hybrid MADM approach. The main categories used for evaluation in this paper are composed of economy, security, technology, global effects, and human wellbeing, while the prioritization criteria were grouped into four categories: namely, benefits, opportunities, costs, risks (BOCR). Özkan et al. [35] developed a fuzzy hybrid MADM method to determine the most suitable energy storage alternative, using four categories of socio-political, environmental, cost, and technical impacts and 18 sub-criteria. In Ref [36], Tan et al. provided a number of quantitative approaches and descriptive statistics to choose the optimal alternative from energy sources.

A review on the literature and research studies results in extracting a wide range of attributes. Analyzing these attributes, measuring the values of each importance, and also determining their frequency in various articles will enable us to identify the basic attributes. Then, these attributes are localized and finalized through interviewing renewable energy experts. Accordingly, Table 10.1 shows the criteria and sub-criteria provided for the selection of the best-established means for generating electricity from renewable energy sources. These attributes are organized into four main categories, technological, economic, environmental, and social, consisting of 20 attributes. As shown in Table 10.1, the classification and related attributes are used in many articles previously [2, 30, 36]. This list was further modified through focus groups discussions and incorporating expert opinions.

Table 10.1 Classification of criteria for selection of appropriate renewable energy source to generate electricity

Main criteria	Sub-criteria	References
Technological	Efficiency	[30, 32, 33, 35]
	Energy (rational) efficiency	[29–31, 34, 35]
	Potential	[29, 30, 34]
	Safety	[30]
	Reliability	[27, 30, 32]
	Electricity generating	[30]
Economic	Investment cost	[28–35]
	Operation and maintenance cost	[29, 30, 35]
	Buy cost	[27, 28, 30, 33, 35]
	Payback period	[2, 29, 30]
	Useful life	[30]
Environmental	NOx emission	[27, 28, 30–32]
	CO2 emission	[27, 28, 30–33]
	SO2 emission	[27, 28, 30–32]
	Particles emission	[30–32]
	Methane	[30–32]
	Land use	[27, 30, 32–34]
	Noise pollution	[30]
Social	Social acceptability	[27, 30, 32, 35]
	Job creation	[28, 30, 32–34]

10.3 Methodology

This is an applied quantitative research study, using CCSD and COPRAS methods for data analysis. The paper covers five basic steps as following. First, a review of previous studies in the field of energy is presented, and the essential attribute for decision-making is extracted. Next, the attributes are localized and finalized through expert interviews, and the categories are approved as the framework. Once the attributes are identified and the final model is achieved, we must select our alternatives.

Different energy sources can contribute to a sustainable electricity generation system; then various electricity generation potential, along with any likely shortcoming, were discussed by experts; and finally, four major resources—wind power, solar energy, biomass, and hydroelectricity—are considered.

In this line, the necessary analysis is then conducted for the alternatives by new MADM methods. Ultimately, the outcomes are evaluated to select the best alternative. Figure 10.1 shows the flowchart of the procedure used in this paper.

There were totally eight professionals with the experience of planning and investing in energy sources from the industry experts, such as the experts of Renewable Energy and Energy Efficiency Organization (SANA Co.) and the academic circles from Tehran University.

Fig. 10.1 Research methodology

10.3.1 Correlation Coefficient and Standard Deviation Approach[1]

This new method proposes a correlation coefficient (CC) and standard deviation (SD) integrated approach for determining weights of attributes. Below is a description of the correlation coefficient and standard deviation (CCSD) method [37].

Suppose that there are n decision alternatives, $A_1, \ldots, A_n$, which are assessed based on m attributes, $O_1, \ldots, O_m$. The alternatives' evaluation forms a decision matrix, that is represented as $X = (x_{ij})_{n \times m}$, where x_{ij} indicates the performance of alternative A_i with respect to the attribute O_j. The m attributes can be divided into two major categories: cost and benefit. The benefit attributes are recognized as those attributes for which maximization is generally preferred, such as profit, income, quality, and so on. However, the cost attributes are recognized as those attributes for which minimization is generally preferred, such as cost, instability, crime rate, and so on.

The incommensurability between attributes with different measure unites calls for normalization of the decision matrix $X = (x_{ij})_{n \times m}$. The most widely used form in the normalization process is given as:

$$z_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}}, \quad i = 1, \ldots, n; \; j \in \Omega_b \tag{10.1}$$

$$z_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}}, \quad i = 1, \ldots, n; \; j \in \Omega_c \tag{10.2}$$

where $x_j^{\max} = \max\limits_{1 \le i \le n} \{x_{ij}\}, x_j^{\min} = \min\limits_{1 \le i \le n} \{x_{ij}\}$, and Ω_b and Ω_c denote the index sets of benefit and cost attributes, respectively. A normalized decision matrix whose elements are defined as z_{ij} can be computed by:

[1] CCSD.

$$Z = \left(z_{ij}\right)_{n\times m} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_{\mathrm{n}} \end{array} \begin{array}{c} \begin{array}{cccc} O_1 & O_2 & \dots & O_m \end{array} \\ \begin{bmatrix} z_{11} & z_{12} & \dots & z_{1m} \\ z_{21} & z_{22} & \dots & z_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ z_{n1} & z_{n2} & \dots & z_{nm} \end{bmatrix} \end{array} \tag{10.3}$$

Now, for the weight vector of attributes, $W = (w_1, \ \dots, w_m)$, which satisfies $W \geq 0$, we have:

$$\sum_{j=1}^{m} w_j = 1 \tag{10.4}$$

According to the simple additive weighting (SAW) method from the MADM approach, the assessed value for each decision alternative is calculated as follows [38]:

$$d_i = \sum_{j=1}^{m} z_{ij} w_j, \ \ i = 1, \dots, n \tag{10.5}$$

This is a linear function of attribute weights. The higher the assessed value, the better utility the decision alternative would have. The best decision alternative provides the greatest overall assessment value. Here, the attribute O_j is removed to address its impact on decision-making. Once O_j is deleted, the overall assessment values for each decision alternative are redefined as follows:

$$d_{ij} = \sum_{k=1,\, k\neq \mathrm{j}}^{m} z_{ik} w_k, \ \ i = 1, \dots, n \tag{10.6}$$

The correlation coefficient between the value of the attribute O_j and the above-mentioned overall assessment value can be expressed as:

$$R_j = \frac{\sum_{i=1}^{n} \left(z_{ij} - \bar{z}_j\right)\left(d_{ij} - \bar{d}_j\right)}{\sqrt{\sum_{i=1}^{n} \left(z_{ij} - \bar{z}_j\right)^2 . \sum_{i=1}^{n} \left(d_{ij} - \bar{d}_j\right)^2}}, \ j = 1, \dots, m \tag{10.7}$$

where

$$\bar{z}_j = \frac{1}{n} \sum_{i=1}^{n} z_{ij}, \ j = 1, \dots, m \tag{10.8}$$

$$\bar{d}_j = \frac{1}{n}\sum_{i=1}^{n} d_{ij} = \sum_{k=1,\, k\neq j}^{m} \bar{z}_k w_k,\ j = 1, \ldots, m \tag{10.9}$$

If R_j is high enough to be close to 1, then O_j and the overall assessment value with an exclusion of O_j will have the same numerical distributions and rankings. Here, the removal of O_j exerts little influence on decision-making, and a small weight is therefore assigned to O_j. If R_j is little enough to be close to 0, then O_j and the overall assessment value with an exclusion of O_j will find opposite numerical distributions and rankings. In this case, the removal of O_j has great influence on decision-making and, therefore, a high weight is assigned to O_j. Further, when one attribute shows the same effect with all alternatives, it is possible to delete that attribute without affecting decision-making. In other words, the attributes with larger standard deviations (SDs) must be assigned higher weights than those attributes with smaller SDs.

According to the analysis above, the attribute weights are expressed as:

$$w_j = \frac{\sigma_j\sqrt{1 - R_j}}{\sum_{k=1}^{m} \sigma_k\sqrt{1 - R_k}},\ j = 1, \ldots, m \tag{10.10}$$

where σ_j is the standard deviation of attribute O_j, given by:

$$\sigma_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(z_{ij} - \bar{z}_j\right)^2},\ j = 1, \ldots, m \tag{10.11}$$

And, the square root of $1 - R_j$ is found to reduce the difference between the largest and smallest values of weight. Otherwise, a bigger difference between the largest and smallest weights will be observed (10.10) in a non-linear system of equations. It includes m equations which are uniquely determined by m weight variables. To solve this system of equations, it is possible to form a non-linear optimization model as follows:

$$\text{Minimize } J = \sum_{j=1}^{m}\left(w_j - \frac{\sigma_j\sqrt{1 - R_j}}{\sum_{k=1}^{m} \sigma_k\sqrt{1 - R_k}}\right)^2$$

$$\text{Subject to } \sum_{j=1}^{m} w_j = 1 \qquad w_j \geq 0,\ j = 1, \ldots, m \tag{10.12}$$

Next, the non-linear model can be solved using Matlab or LINGO software packages, and the weights of each attribute are extracted.

10.3.2 Complex Proportional Assessment Method

Decision analysis deals with a decision situation under which decision-makers need to select the best alternative from a broad set of conflicting criteria [39]. In such circumstances, the method of complex proportional assessment (COPRAS) developed by Zavadskas and Kaklauskas can be applied [40]. The COPRAS method has been commonly used in a wide range of construction problems [41–44].

The procedure of the COPRAS method covers the following steps [45]:

Step 1: Selecting the set of the most important attributes, which best describes the alternatives.

Step 2: Constructing the decision-making matrix X.

$$X = \begin{bmatrix} [x_{11}] & \cdots & \cdots & [x_{1m}] \\ [x_{21}] & \cdots & \cdots & [x_{2m}] \\ \ddots & \cdots & \ddots & \vdots \\ [x_{n1}] & \cdots & \cdots & [x_{nm}] \end{bmatrix}; \; j = \overline{1,n} \;\; i = \overline{1,m} \tag{10.13}$$

Step 3: Determining the importance (weight) of the attribute q_i.

Step 4: Normalizing the decision-making matrix X by using Eq. (10.14).

$$\tilde{x}_{ji} = \frac{\tilde{x}_{ji}}{\sum_{j=1}^{n} \tilde{x}_{ji}} \quad j = \overline{1,n}; \; \mathrm{i} = \overline{1,m} \tag{10.14}$$

In Eq. (10.2), $\underline{x}_{ji}$ is the lower bound for the i_{th} attribute of the j_{th} alternative. Moreover, $\bar{x}_{ji}$ is the upper bound for the i_{th} attribute of the j_{th} alternative.

m and n represent the numbers of attributes and alternatives, respectively. Hence, the normalized decision-making matrix is:

$$\tilde{X} = \begin{bmatrix} [\tilde{x}_{11}] & [\tilde{x}_{12}] & \cdots & [\tilde{x}_{1\mathrm{m}}] \\ [\tilde{x}_{21}] & [\tilde{x}_{22}] & \cdots & [\tilde{x}_{2\mathrm{m}}] \\ \vdots & \vdots & \ddots & \vdots \\ [\tilde{x}_{n1}] & [\tilde{x}_{n2}] & \cdots & [\tilde{x}_{nm}] \end{bmatrix} \tag{10.15}$$

Step 5: Calculating the weighted normalized decision-making matrix $\hat{X}$. The weighted normalized value $\hat{x}_{ji}$ is computed as follows:

$$\hat{x}_{ji} = \tilde{x}_{ji} \cdot q_i \tag{10.16}$$

where q_i is the weight of the ith attribute. Therefore, the weighted decision-making matrix is:

$$\hat{X} = \begin{bmatrix} [\hat{x}_{11}] & [\hat{x}_{12}] & \cdots & [\hat{x}_{1m}] \\ [\hat{x}_{21}] & [\hat{x}_{22}] & \cdots & [\hat{x}_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\hat{x}_{n1}] & [\hat{x}_{n1}] & \cdots & [\hat{x}_{nm}] \end{bmatrix} \tag{10.17}$$

Step 6: Calculating the value of P_j as below, whose larger values have higher priority.

$$P_j = \sum_{i=1}^{k} \hat{x}_{ji} \tag{10.18}$$

Step 7: Calculating the value of R_j as below, whose larger values have higher priority.

$$R_j = \sum_{i=k+1}^{m} \hat{x}_{ji} \qquad i = \overline{k, m} \tag{10.19}$$

In Eq. (10.7), $m - k$ is the number of attributes to be minimized (i.e., cost-type attributes).

Step 8: Determining the minimal value of R_j.

$$R_{\min} = \min_j R_j, \;\; j = \overline{1, n} \tag{10.20}$$

Step 9: Calculating the relative importance of each alternative, Q_j, as follows:

$$Q_j = P_j + \frac{\sum_{j=1}^{n} R_j}{R_j \sum_{j=1}^{n} 1/R_j} \tag{10.21}$$

Step 10: Determining the optimality criterion K:

$$K = \max_j Q_j, \;\; j = \overline{1, n} \tag{10.22}$$

Step 11: Determining the priority of the alternatives.
Step 12: Calculating the utility degree of each alternative:

$$N_j = \frac{Q_j}{Q_{\max}} \times 100\% \tag{10.23}$$

where Q_j and $Q_{\max}$ are the importance of alternatives obtained from Eq. (10.21).

Based on the descriptions given for the CCSD and COPRAS methods, below are the application procedures for these methods to determine the weights of attributes and alternatives. To this end, Table 10.2 shows the decision table with the specified alternatives for rankings and the attributes for alternative evaluation.

According to Table 10.2, the weights of attributes can be determined by using Eqs. (10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 10.10, 10.11, and 10.12) in the CCSD integrated approach, shown in Table 10.3, as follows:

Based on the decision-making matrix in Table 10.2, the normalized values of this matrix are calculated by Eq. (10.14). Then, the normalized decision-making matrix is:

Using Eq. (10.16) and Table 10.2, the weighted normalized matrix is calculated (See Table 10.4). Note that in Eq. (10.16), q_i is the weight of the ith attribute, as shown in Table 10.3.

Next, the values of P and R are determined using Eqs. (10.18) and (10.19), while the values of N and Q can be calculated by Eqs. (10.21) and (10.23). Ultimately, Table 10.5 represents the final ranking for the alternatives.

10.4 Conclusion

As stated, the increasing use of renewable energies and the replacement of current polluting energy sources are of great importance [1]. Selecting the best from various renewable energy sources requires that different groups of decision-makers become involved in the process. As social, economic, technological, and environmental factors need to be taken into consideration in decision-making, so the process is more complex, and then traditional single-criterion decision-making is no longer able to handle these problems properly. Thus, the MADM techniques can have a significant contribution toward such decisions.

This paper aims to select a proper energy source for electricity generation. First, the literature review was conducted to select appropriate energy sources, and to identify measure attributes and evaluation alternatives. Then, the attributes were localized and finalized through interviews of the experts in the renewable energy field (eight professionals with the experience of planning and investing in energy sources from the industry experts and the academic circles form University). In order to select the best-established source, the alternatives for the production of electricity were determined through focus groups discussions and incorporating expert opinions. The specified alternatives included wind power, solar energy, biomass, and hydroelectricity.

Table 10.2 A decision matrix

	Criteria	Efficiency	Exergy (rational) efficiency	Potential	Safety	Reliability	Electricity Generating	Investment cost	Operation and maintenance cost	Buy cost	Payback period
	Criteria Number	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10
	Criteria Type	Positive	Positive	Positive	Positive	Positive	Positive	Negative	Negative	Negative	Negative
Alternatives	Biomass	0.27	0.79	800	3	9	3	300,000	4.5	440	7
	Wind	0.85	0.49	100,000	9	3	100	1,400,000	1.5	463	5
	Solar	0.2	0.1	60,000	9	3	0.25	10,420	0.3	463	5
	Hydropower	0.9	0.45	50,000	5	9	1500	35,000,000	0.34	463	7
	Criteria	Useful life	NOx emission	CO_2 emission	SO_2 emission	Particles emission	Methane	Land use	Noise pollution	Social acceptability	Job creation
	Criteria number	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20
	Criteria type	Positive	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Positive	Positive
Alternatives	Biomass	30	6	5700	9.4	10,500	1	3	1	1	650
	Wind	20	0	0	0	0	0	160	1	5	1900
	Solar	25	0	0	0	0	0	30	0	7	220
	Hydropower	50	0	0	0	0	0	638,800	0	5	40,000

Table 10.3 Attribute weights using CCSD

Criteria number	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10
Criteria weight	0.051	0.036	0.036	0.051	0.058	0.035	0.059	0.052	0.036	0.058
Criteria number	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20
Criteria weight	0.033	0.061	0.061	0.061	0.061	0.061	0.061	0.058	0.040	0.035

Once integrated and modified by experts, the attributes derived from the literature review were organized by technological, economic, environmental, and social categories. A number of 20 sub-criteria were assigned to them. After finalizing the attributes and evaluating the energy alternatives, the decision-making matrix was formed by the experts' opinions. Then, the CCSD and COPRAS methods were used to weight and select the good alternative for energy. Table 10.5 represents the results.

According to the values obtained from the CCSD integrated approach in Table 10.3, the highest weight of the existing attributes is generally related to the environmental category. This highlights the importance of reducing emissions with the use of renewable energy sources. Following it, the rate of return on investment, investment cost, and reliability have the highest weights. However, it reflects only the greater influence of these attributes over decision-making, rather than the lack of importance for other attributes. Meanwhile, the index of useful life takes the smallest level of importance. The emphasis on these criteria and subsequent sub-criteria demonstrates that environmental and financial risk aversion is vital in energy planning.

Table 10.5 enables energy field managers to select the best-established means for electricity generation. It reports the priority of each alternative; the solar energy has the highest level of priority, followed by wind power and hydroelectricity. The lowest priority is assigned to biomass.

This suggests the need for a set of interventions to address solar energy solutions, and to build and develop solar energy infrastructure for electricity generation. Additionally, wind power can also be considered as a suitable alternative. It will significantly contribute to reducing costs, enhancing capabilities, and avoidance of wasting resources.

10.5 Future Studies

The literature indicates the important role of addressing decision-making problems based on the MADM methods. Therefore, more accurate outcomes for selecting and planning energy sources require wider studies on the application of new methods for

Table 10.4 Normalized decision matrix

	Criteria number	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10
Alternatives	Biomass	0.122	0.432	0.003795	0.115	0.375	0.00187	0.00817	0.678	0.241	0.292
	Wind	0.383	0.268	0.474383	0.346	0.125	0.06237	0.03814	0.226	0.253	0.208
	Solar	0.09	0.055	0.28463	0.346	0.125	0.00016	0.00028	0.045	0.253	0.208
	Hydropower	0.405	0.246	0.237192	0.192	0.375	0.93560	0.95341	0.051	0.253	0.292
	Criteria number	x11	x12	x13	x14	x15	x16	x17	x18	x19	x20
Alternatives	Biomass	0.24	1	1	1	1	1	0.000005	0.5	0.056	0.015
	Wind	0.16	0	0	0	0	0	0.000250	0.5	0.278	0.044
	Solar	0.2	0	0	0	0	0	0.000047	0	0.389	0.005
	Hydropower	0.4	0	0	0	0	0	0.999698	0	0.278	0.935

Table 10.5 Final outcomes and alternative rankings

		P	*R*	*Q*	*N*	Rank
Alternatives	Biomass	0.06	0.393	0.08343	18.2	4
	Wind	0.091	0.064	0.235716	51.43	2
	Solar	0.064	0.023	0.458308	100	1
	Hydropower	0.159	0.145	0.222545	48.56	3

weighting and decision-making. Further, these approaches can be used with similar fields such as decision-making and selecting appropriate wind turbine technologies. In addition to the importance of addressing this issue in academic and scientific areas of study, it is recommended to include such planning activities in research topics and priorities of the country.

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Chapter 11
Selection of Gamification Elements for Demand Side Energy Management: An Application Using Hesitant Fuzzy AHP

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11.1 Introduction

Throughout decades, electric distributed systems that have been managed manually by human hands have been a significant and pressing issue [1]. The main goal is to maintain safe working conditions by supplying the required energy. It is especially important for peak demand periods. The peak demand occurs at high gigawatt intervals for a short period, and supply side requires power sources, such as natural gas plants, hydroelectric power plants, and diesel generator, that can be easily activated [2]. Since demand peak lasts for a short period, these power plants remain idle after supplying the peak demand.

Another way of dealing with peak demand is manipulating the demand for energy. Energy Demand Side Management (EDSM) aims to encourage customers to use less energy during the peak hours. EDSM's main advantage is that it is less expensive to influence a load intelligently than to build a new power plant or install some electric storage device [3]. Thus, EDSM stands out to promise solutions for problems of girds with a new approach but also bringing new challenges. One of EDSM methods is Direct Load Control (DLC) which is based on directly managing local and central controllers and regulates energy demand. Another approach is Indirect Load Control (ILC) which indirectly manipulates customers' behaviors by using incentives, tariffs, and additional payments.

EDSM enables organizations to gain an overall view of the network's burden, create load profiles, and control production-driven consumption [4]. In this way, peak demand consumption is reduced, network interruptions are prevented, and a better

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basis for investment planning is created [5, 6]. EDSM can be used for other different purposes such as peak load shifting [7–10], peak clip-ping [11], strategic conservation, strategic load growth [12], valley filling [11], and flexible load shape [13].

Gamification is the application of game-design elements and game principles in non-game contexts. Gamification commonly employs game design elements out of game context, so it should be designed as if it is a game [14]. The most important factor to maintain a perfect user experience is the game design [15]. Among the design factors, level of competition, story, target players, and activities are the most important ones. As a part of the experience, the fun and the level of competition are needed to set very well [16]. The story needs to fit in with goals and support the behavioral change. The target players have to be defined with a comprehensive profile definition. At the same time, the required user activities and their frequencies should be determined. Finally, the goal, the creation of the content and the definition of the feedback mechanisms, need to be completed [17].

Gamification is defined as “the process of adding games or game like elements to something (such as a task) to encourage participation” (Merriam-Webster). Gamification can be thought of as an interventional tool aimed at promoting certain desired behaviors by touching internal motivation [18]. In energy management, integrating internet of things based research with a gamification approach has a potential to change and protect the behavior of energy consumption. In a recent study, Papaioannou et al. [18] show a case study by investigating energy consumption in public buildings and suggest a framework aimed at making it easier to reduce energy efficiency and wasted energy. Gamification approaches use game-like elements to achieve its goals such as feedback, tips, points, avatars, and rewards. Systems can be designed using only one element of a combination of elements. In the literature, some of the studies use only a single gamification element [19–21]. In many other studies, more than one gamification element is integrated into a system [22–25].

Gamification can be effectively used to manipulate energy consumption by integrating information systems and intelligent networks. Internet-based platforms with large databases are needed to take part in such an approach. The intelligent network can gather data from the intelligent machines such as refrigerators [26] and washing machines [27, 28] and report up-to-date energy consumption data to the user via the internet. When such an integration is maintained, “gamification” can be used to motivate users to control machines and manipulate energy consumption remotely. In such an architecture, intelligent networks can also make recommendations or automatically give decisions.

The main goal of this chapter is to investigate gamification applications in energy management and provide a multi-criteria decision model for the design of a new gamification approach for EDSM. Since gamification involves various elements, such as badges, leaderboards, rankings, etc., there exist various design alternatives for system development. Selection of the appropriate design alternative is a multi-criteria group decision process since it involves various criteria and judgments from different decision makers. Multi-criteria decision-making (MCDM) focuses on problems with discrete decision spaces and predefined decision alternatives.

Traditionally, MCDM methods represent decision-makers' evaluations by numerical numbers and reach a result after mathematical operations. To this end, the decision makers either assign numerical values directly or use linguistic terms that are then converted to crisp numbers. However, in real-world applications, both cases may cause loss of information. Fuzzy sets have been adopted to MCDM problems to overcome this problem [29, 30]. Decision problems have been studied by using extensions of fuzzy sets such as Type-2 fuzzy sets [31, 32], intuitionistic fuzzy sets [33, 34], interval-valued intuitionistic fuzzy sets [35, 36] that have also been used for decision-making problems. One of the most recent extensions of fuzzy sets is the hesitant fuzzy sets (HFS) proposed [37]. HFS provides a structured approach to represent decision-makers' evaluations since it empowers membership value of an item to take more than one value. Using HFS in a decision model, decision makers' hesitancy is better communicated into the decision problem [38, 39].

In this paper, a group decision-making model is proposed based on Hesitant Fuzzy Analytic Hierarchy Process [40, 41] for gamification design problem. In cases, where multiple experts are involved in the decision model, it is very rare for the experts to come up with the same evaluations. In such cases, different evaluations can be expressed joint membership degree. This joint membership degree may be defined as an interval such as "between good and very good" or "at most very good" rather than a single linguistic term. The proposed decision model can process such interval linguistic terms to select the best gamification design.

The rest of the chapter is as follows. Section 11.2 presents the basic definitions of gamification. Section 11.3 gives a brief literature review on gamification in energy studies. Section 11.4 introduces hesitant fuzzy sets and briefly explains the methodology. Section 11.5 summarizes the decision models with alternatives and decision criteria. Section 11.6 provides a numerical application of the problem. In the last section, the results are discussed, and suggestions for future studies are given.

11.2 Gamification

Gamification is a growing knowledge-based approach for promotive user motivation, engagement, and enjoyment in non-gaming and computer-mediated atmospheres with an early collection of experimental work supporting its potential for beneficial effects in certain contexts [42]. The gamification is a discipline in which game designs and game mechanics are added to an out-of-play process [17]. Participants turn to players, concentrate on the activities they need to do in the game dynamics with higher motivation. Besides, they participate in volunteering with more enjoyment.

Gamification consists of three main layers from structure to design. They are dynamics, mechanics, and components [43]. Dynamics are design solutions which are independent of game rules in gamification areas. They include some elements such as storytelling, player mode, goals, selection, and rules. In this way, the design of dynamics has to comprise the users' attributes, which have to be updated through the progress within the gamified system. Mechanics feed the components that the end user sees with the reference that it receives from the dynamic to be complementary [44]. They are the emotional part where the player fully interacts with the application. Mechanics have some elements such as chances, challenges, competition, team, feedback, reward, sources, interactions, turn, and winning status. It is the mechanics that motivates and promotes the component. The components are the design objects that the end users see. They are integrated with the playing process [17]. The components are composed of an avatar, badges, points, level of player, virtual incomes, treatments, social sharing, leaderboard, and collect and trade.

The simplest and most commonly used game mechanics is the "points" [17]. Even if the users do not know pointing mechanism, their actions are translated into points and can be shown as a score. Ranking allows some form of competitiveness by allowing players to compare their points with those obtained by their colleagues.

The purpose of a "leaderboard" is to show players where they are ranked in a gamified system [45]. The leaderboard can be used in different ways such as locally, socially, time, and contextually. "Badges" are also one of the most common mechanics investigated in gamification studies [46]. Users could unlock badges by completing common actions and tasks. Besides, badges consist of optional rewards [47]. The players must be given a "level" and a "goal" so that they can differentiate according to their knowledge and experience and can make special applications to them [17]. These levels should be arranged in such a way that the player must accomplish some tasks to pass to the next levels. Accomplishing tasks as a "team" is important since collective efficacy influences the team to initiate action, and increase the amount of effort the team members will sustain [48]. Participating in a team supplies comparing and competing for success with users' teammates and getting additional points with successive participation in successive events.

In gamification, "challenge" is defined as a promise which is accepted and given to the player in a game at a certain value, if the player completes the predetermined task. It is a good explanatory example of weight loss: when people compete against each other. Users can challenge with their friends to achieve many points in a period; besides, it is a chance to compare themselves with their friends [49]. Another element of gamification is "Feedback" and seen as the backbone of gamification [17]. When people do something, giving a feedback motivates players for the next step. Feedback with a positive appreciation in the positive actions of the players and feedback with a clue as to how to reverse the behavior in the negative case contribute to the player's self-development and provide extra motivation. "Reward" is also a very important element in gamification. Not only classic gamification but also in all games, achieving the desired result and winning a reward is a conclusion of the achievement [49]. Indeed, the result is that many applications also use this motivational reward in fiction. As a strong motivational element, the reward is a very suitable mechanics for the suitability of the player. When the tasks are completed, the game fiction passes on life, and the targets occur. It is a great contribution to being able to see the goals collectively and understand where the player is in the big picture concerning the goal.

Competition gives people a chance to prove themselves against others [23]. It can be a way to win rewards, but it can also be a place where new friendships and relationships are born. Since many people love to collect and exchange things, gamification provides a way to collect and trade items in the system. It helps to establish relationships among other players. Building relationship allows people an accessible social sharing [22]. The social sharing affects other game mechanics such as competition and rankings, so players will see a ranking comparing them with the other players [49]. While avatars help individuals to project their alter-egos or boost their esteem, they play a very critical role in enhancing learner engagement in the gamification systems [50]. A gamification system can tell a story and let people tell theirs because of strengthening understanding of the story by involving people [51].

11.3 Literature Review

The literature provides various gamification applications which focus on user behaviors. The application areas include education [21, 52, 53], tourism [54, 55], healthcare [56, 57], banking [58, 59], production and service industry [60], and energy [22–24]. These studies usually focus on indicating benefits of games together with some empirical evidence.

To measure outcomes of gamification application, different data collection methods are preferred. According to the literature review, the most common data collection methods in energy domain are grouped into six categories: Quantitative, quasi-experimental (between-participants) design, questionnaire, mixed methods, survey, interviews, energy meters (in energy areas) [22, 24, 25].

Johnson et al. [1] divide the outputs of a gamification system into five groups. These groups are: user experience [23], cognitive (attitude, motivation, awareness) [22, 24], behavioral (real world) [24], behavioral (in game) [23], and knowledge [61]. User experience and behavior (in the game) are positive outputs in all implementations. Also, almost none of the studies refers a negative output.

Some authors use different gamification elements in their studies to change behaviors of users. They can be listed as achievement: avatar, badge, challenges, feedback, goal, leaderboard, level, point, ranking, rewards or penalty, social sharing, story, and tip [17, 62–64]. The number of studies, which focus on a comparison of effects of different gamification elements, is limited. Gustafsson et al. [65] and Senbel et al. [66] prove that social sharing and challenge encourage users. Also, Senbel et al. [66] show points and rewards should be chosen as an initial incentive, but other elements such as challenge and leaderboard are more useful throughout participation. There is no study investigating which gamification elements should be together in the literature.

De Vries and Knol [22], Geelen et al. [24], Knol and De Vries [67], Lee et al. [68], Mesquita et al. [21], Peham et al. [25], Buchanan et al. [61], Gustafsson et al. [65] focus on energy in their studies. All of them provide evidence for positive effects of gamification elements on the energy-saving behavior of users concerning several outputs such as user experience, cognitive (motivation, attitude), behavior (in-game and real world). Gamberini et al. [23] study on assessment of the game usability.

On the other hand, Guin et al. [50], Halan et al. [69], Fitz-Walter et al. [53], Eickhoff et al. [70], Li et al. [71], Domínguez et al. [52] concentrate on users' satisfaction, motivation, and engagement in different gamification areas.

While Hamari [72] improves social interactions among participants using badge and goal elements, Cheong et al. [73] increased learning quality by implementing gamification elements: challenge, feedback, points, leaderboard.

The literature review on gamification in the energy sector can be summarized as shown in Table 11.1.

11.4 Hesitant Fuzzy AHP

Design of a new gamification approach for EDSM information system involves various decisions. One of the most important decisions is a selection of the appropriate gamification element. The selection problem is an MCDM problem since it involves selection of the best alternative using various criteria and judgments from different decision makers. Traditional MCDM methods, such as Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity To Ideal Solution (TOPSIS), and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), have been extended by using fuzzy sets to handle expert evaluations in a better way. Recently, new extensions of ordinary fuzzy sets have been proposed to involve decision makers' hesitancy into the decision model. One of the most recent fuzzy set extensions is Hesitant Fuzzy Sets (HFSs). HFSs have been introduced by Torra [37] for cases where defining the membership degree of an element is not easy since several possible membership values may exist. Based on HFS, Rodriguez et al. [74] introduced the concept of a hesitant fuzzy linguistic term set (HFLTS) to provide a linguistic and computational basis to increase the richness of linguistic elicitation based on context-free grammars by using comparative terms.

Let X be a fixed set, a hesitant fuzzy set (HFS) on X is regarding a function that when applied to X returns a subset of [0, 1] [37].

Mathematical expression for HFS is as follows:

$$E = \{< x, h_E(x) > | x \epsilon X \}, \tag{11.1}$$

where $h_E(x)$ is a set of some values in [0, 1], denoting the possible membership degrees of the element $x \epsilon X$ to the set E. Some basic definition about h is as follows:

Table 11.1 Literature review on gamification

Study	Aim	Data collection	Gamification element(s) and incentive to play	Strategy	Metrics of evaluation	Outcomes (effect +/−)	Results
De Vries and Knol [22]	Examine effectiveness of the game on several energy-related attitudes	Quantitative, quasi experimental (between-participants) design; questionnaire	Levels, social sharing, points, rewards	Each player has own strategies to build structures	Saving energy at home, switching off lights in unoccupied rooms, turning off TVs rather than using standby functions, taking shorter showers	Cognitive (attitudes) (+)	Significant increase in attitudes towards saving energy and performing specific energy-related household behaviors. ANOVA was used
Geelen et al. [24]	To encourage home occupants to save energy	Mixed methods, survey, pre-post testing; questionnaire, interviews, energy meters	Feedback, rankings, rewards	To encourage home occupants to save energy	Average energy savings,energy consumption,	Cognitive (motivation) (+)	Household energy consumption reduced during gameplay and remained below baseline directly post-intervention for 6/10 households
						Behavioral (real world) (+)	Participation motivated by prizes and potential energy savings. Direct feedback and prizes were the most motivating game elements for energy saving

(continued)

Table 11.1 (continued)

Study	Aim	Data collection	Gamification element(s) and incentive to play	Strategy	Metrics of evaluation	Outcomes (effect +/−)	Results
Gamberini et al. [23]	To assess the satisfaction/ acceptance and usability of the game	Mixed methods, field study; questionnaire, interviews, access logs	Feedback, challenges, social sharing, rewards	To increase energy awareness and saving in the household	Pleasantnessusab-ilityusage purpose	User experience (+)	Positive results for acceptance and usability of application
						Behavioral (in game) (+)	Perceived as useful in the management and awareness of energy consumption and effective in changing consumption habits
Knol and De Vries [67]	Examine if game can offer engaging environment to encourage learning about energy saving	Mixed methods, quasi experimental (between-participants) design; questionnaire	Levels, social sharing, rewards	To evaluate the increasing awareness and attitudes relating to energy use in the household	Energy games played by students,qualitative impressions on students, effects on environmental awareness ofstudents,effects on energy saving attitudes	User experience (+)	Increase in awareness of energy and environmental related issues and improvement in attitudes towards behaviors relating to household energy consumption
Lee et al. [68]	To describe an open source game engine, developed for a residence hall energy	Mixed methods, survey; questionnaire, interviews, in-game tracking	Points, levels, challenges, rewards, feedback, badges, leaderboards	To motivate players to learn about energy issues, to improve their intuition about	Usability evaluations in game design,active participation rate	User experience (+)	Positive user experience and attitudes towards game

	competition, for energy education and conservation			energy consumption,to understand how to use energy more efficiently in their normal life			
Mesquita et al. [21]	To present an assessment of an educational game for teaching the efficient use of electricity	Quantitative, survey, questionnaire	Challenges, competition	To present an assessment of an educational game for teaching the efficient use of electricity with an educational game	A questionnaire was used to evaluate the results about kowledge, understanding and application	Cognitive (motivation) (+)	Social interaction/ sharing identified as powerful game feature in terms of motivating action
						User experience (+)	Increase in participants ability to retain, discuss and apply information related to the game theme
Peham et al. [25]	To support consumer awareness of energy efficient purchase and use of products, enhancing energy-aware and ecologically sound behavior in everyday life	Mixed methods, survey, usability testing; questionnaire, task series, interviews	Rewards, points, levels, leaderboards, challenges	To support consumer awareness of energy efficient purchase and use of products, enhancing energy-aware and ecologically sound behavior in everyday life	Before and after test a questionnaire and during the test a case study was used	User experience (+)	Perceived as user-friendly and useful for learning about energy saving
						Cognitive (motivation) (+)	Found to be most successful for individuals already sensitive to energy saving

(continued)

Table 11.1 (continued)

Study	Aim	Data collection	Gamification element(s) and incentive to play	Strategy	Metrics of evaluation	Outcomes (effect +/−)	Results
Buchanan et al. [61]	To learn what is needed to secure acceptance and engagement from domestic consumers with services, products and offers in smarter power systems	Mixed methods, Quasiexperimental (between-participants) design; questionnaire, interviews, energy meters	Point, reward, social sharing	To examine consumer acceptance of smart metering initiatives using focus groups	Being active member of the community,learning how to reduce energy use	User experience (+/−)	There was less appetite for this learning to occur in a home environment
						Knowledge (−)	Gamification encountered resistance due to a lack of consumer appeal
Guin et al. [50]	To improve satisfaction and engagement on surveys	Quantitative, implementation, experiment, survey	Avatar, reward, story	To systematically test the impact of different presentation styles including some gamification elements they designed and conducted an online survey	A questionnaire was used to evaluate the results	User experience (+)	Gamified survey cells were more satisfied than those in the other two survey cells. The gamified presentation consumed more than twice
Halan et al. [69]	To improve user motivation and participation in the conversational modeling	Mixed methods, implementation, experiment, examination of initial responses	Leaderboard, story	To evaluate the applicability of some gamification elements through a user	The ratio of interactions,the average time spent	Behavioral (real world) (+)	The motivational strategies were effective in increasing user participation

	for virtual humans			study conducted for modeling the conversational corpus of a virtual patient character			
Hamari [72]	To improve social interactions, usage activity, productive actions	Quantitative, implementation, experiment, design, analysis of use data	Badge, goal	To gamify a utilitarian peer-to-peer trading service by implementing the some game mechanics	Trade proposals per user,accepted transaction per user,comments per user,page views per user	Behavioral (real world) (+/−)	Implementation of gamification mechanisms does not automatically lead to significant increases in user activity in the studied utilitarian service, however, those users who actively monitored their badges and those of others in the study showed increased user activity. ANOVA and MANOVA was used
Fitz-Walter et al. [53]	Using gamification to engage university students	Quantitative, implementation, questionnaire	Badge, goal	To explore the use of game achievements when applied to a mobile application designed to help new students at university	Usage achievements to encourage use,usability vs. enjoyment,	User experience (+/−)	Game elements were well received by the students however there are potential conflicting issues that arise when using game elements that should be considered

(continued)

Table 11.1 (continued)

Study	Aim	Data collection	Gamification element(s) and incentive to play	Strategy	Metrics of evaluation	Outcomes (effect +/−)	Results
Gustafsson et al. [65]	To improve social motivation and changing in relative energy consumption	Mixed methods, implementation, analysis of use data, interviews	Challenge, feedback, leaderboards, level	To build a game which is more casual game play and a richer learning interaction using a real time sensor system	Overall consumption change,attitude changes, learning (the change in scores after versus before the trial)	Behavioral (+)	Statistically significant positive change in the players' attitude toward saving energy
						Knowledge (+)	The direct feedback enriches the learning environment as well as enable appliance level associative learning
Eickhoff et al. [70]	To improve intrinsic-extrinsic motivation to complete tasks in crowdsourcing environment	Quantitative, implementation, experiment, analysis of use data	Challenge, leaderboard, point	The use of a game in order to attract and retain a larger share of reliable workers to frequently requested crowdsourcing tasks such as relevance assessments and clustering	The number of rounds pergame, substantial benefit achieved by offering an alternative incentive to workers	Cognitive (motivation) (+)	Increasing the motivation is done by direct competition or by integrating the game into an identity and reputation-aware environments such as social networks or virtual worlds
Li et al. [71]	To improve engagement, enjoyment and task	Mixed methods, implementation, analysis of user data, interviews	Challenge, feedback, reward, story, goal	To present a gamified interactive tutorial system for first	Completion time and completion rate of the testing tasks,A	Cognitive (motivation) (+)	The learning process is improved by developing challenging levels, providing

	performance in an education environment			time AutoCAD users	questionnaire was filled for qualitative results		motivational feedback and encouraging repetitive task completions
Cheong et al. [73]	To improve the quality of learning by better engaging students with learning activities	Quantitative, implementation, questionnaire	Challenge, feedback, points, leaderboard,	To evaluate a gamified learning activity along the dimensions of learning, engagement, and enjoyment	A questionnaire survey was used to collect data to gauge levels of learning, engagement, and enjoyment	Cognitive (motivation) (+)	Implementation of gamification improve learning and has beneficial effects
Domínguez et al. [52]	In web-based education, to increase student motivation and engagement	Quantitative, implementation, experiment	Badge, feedback, leaderboard, reward	To build a gamification plugin for a well-known e-learning platform	Achievement of students,attitudinal survey,A questionnaire for qualitative analysis	Cognitive (motivation) (+)	Students who completed the gamified experience got better scores in practical assignments and overall score. ANOVA was used

An HFLTS is defined as an ordered finite subset of consecutive linguistic terms of $S = \{s_0, \ldots, s_g\}$ [74]. For instance, let S be defined as $S = \{s_0$: nothing, s_1: very bad, s_2: bad, s_3: medium, s_4: good, s_5: very good, $s_{6:}$ perfect$\}$ and υ be a linguistic variable,

$$H_s(\upsilon) = \{\text{medium}, \text{good}, \text{very good}\}$$

Based on the HFLTS definition, classical Fuzzy Analytic Hierarchy Process (AHP) approach has been extended by Oztaysi et al. [40] and Onar et al. [41]. The hesitant fuzzy AHP model proposed in this chapter is a modification of the papers mentioned above. The steps of the methodology are as follows:

Step 1 Based on literature review and decision makers' evaluations the decision matrix is formed.

Step 2 Decision makers evaluate criteria, sub-criteria, and alternatives using HFLTS and the context-free grammar "between" and "is". Decision makers use the linguistic scale given in Table 11.2 to evaluate the alternative.

Step 3 For each pairwise comparison, decision makers' evaluations are aggregated to obtain pairwise comparison matrix $\tilde{P}$ that is formed as follows;

$$\tilde{P} = \begin{vmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \ldots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \ldots & \tilde{a}_{2n} \\ \vdots & \vdots & \ldots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \ldots & \tilde{a}_{nn} \end{vmatrix} \tag{11.2}$$

In this matrix, $\tilde{a}_{ij}$ represents the HFLTS evaluation on comparison of ith element to jth element. During the aggregation, if decision makers evaluate the same comparison with linguistic terms which re close to each other, then they are aggregated with "between" keyword. If the evaluations are close the situation is shared with the decision maker so that they can discuss and reevaluate the comparison.

Table 11.2 Linguistic scale for hesitant fuzzy AHP

	Linguistic term	Abb.	Triangular fuzzy number
s_{10}	Absolutely high importance	(AHI)	(7,9,9)
s_9	Very high importance	(VHI)	(5,7,9)
s_8	Essentially high importance	(ESHI)	(3,5,7)
s_7	Weakly high importance	(WHI)	(1,3,5)
s_6	Equally high importance	(EHI)	(1,1,3)
s_5	Exactly equal	(EE)	(1,1,1)
s_4	Equally low importance	(ELI)	(0.33,1,1)
s_3	Weakly low importance	(WLI)	(0.2,0.33,1)
s_2	Essentially low importance	(ESLI)	(0.14,0.2,0.33)
s_1	Very low importance	(VLI)	(0.11,0.14,0.2)
s_0	Absolutely low importance	(ALI)	(0.11,0.11,0.14)

Step 4 The matrix ($\tilde{P}$) is transformed to the numerical pairwise comparison matrix ($\tilde{C}$). By using ordered weighted averaging (OWA) and the scale given in Table 11.2 [75].

$$\tilde{C} = \begin{vmatrix} (1,1,1,1) & \tilde{c}_{12} & \dots & \tilde{c}_{1n} \\ \tilde{c}_{21} & (1,1,1,1) & \dots & \tilde{c}_{2n} \\ \vdots & \vdots & \vdots\ \vdots\ \vdots & \vdots \\ \tilde{c}_{n1} & \tilde{c}_{n2} & \dots & (1,1,1,1) \end{vmatrix} \tag{11.3}$$

where $\tilde{c}_{ij} = \left(c_{ij_l}, c_{ij_{m1}}, c_{ij_{m2}}, c_{ij_u}\right)$. The reciprocal of $\tilde{c}_{ij}$ is obtained as follows:

$$\tilde{c}_{ji} = \left(\frac{1}{c_{ij_u}}, \frac{1}{c_{ij_{m2}}}, \frac{1}{c_{ij_{m1}}}, \frac{1}{c_{ij_l}}\right) \tag{11.4}$$

An ordered weighted averaging (OWA) operator is defined as given in Eq. (11.5).

$$\mathrm{OWA}(a_1, a_2, \dots, a_n) = \sum_{j=1}^{n} w_j b_j \tag{11.5}$$

where b_j is the jth largest of the aggregated arguments $a_1, a_2, \dots, a_n$, and $W = (w_1, w_2, \dots, w_n)^T$ is the weighting vector so that $w_i \in [0,1]$, $i = 1, 2, \dots, n$ and $\sum_{i=1}^{n} w_i = 1$.

In our case, the transformation is formed as follows: Assume the scale used by the decision makers contains 11 terms, $s_0 \leq s_i < s_j \leq s_{10}$ and the decision makers' evaluations are "between s_i and s_j" where $s_0 \leq s_i < s_j \leq s_{10}$. The trapezoidal fuzzy number associated with this evaluation will be in the form of $\tilde{c} = (c_l, c_{m1}, c_{m2}, c_r,)$. The parameters of this trapezoidal fuzzy number are calculated as follows:

$$c_l = \min\left\{a_l^i, a_m^i, a_l^{i+1}, \dots, a_m^j, a_u^j\right\} = a_l^i \tag{11.6}$$

$$c_r = \max\left\{a_l^i, a_m^i, a_l^{i+1}, \dots, a_m^j, a_u^j\right\} = a_u^j \tag{11.7}$$

$$c_{m1} = \begin{cases} a_m^i, \ \text{if } i+1=j \\ \mathrm{OWA}_{w^2}\left(a_m^i, \dots, a_m^{\frac{i+j}{2}}\right), \ \text{if } i+j \text{ is even} \\ \mathrm{OWA}_{w^2}\left(a_m^i, \dots, a_m^{\frac{i+j-1}{2}}\right), \ \text{if } i+j \text{ is odd} \end{cases} \tag{11.8}$$

$$c_{m2} = \begin{cases} a_m^{i+1}, \ \text{if } i+1=j \\ \mathrm{OWA}_{w^1}\left(a_m^j, a_m^{j-1}, \dots, a_m^{\frac{i+j}{2}}\right), \ \text{if } i+j \text{ is even} \\ \mathrm{OWA}_{w^1}\left(a_m^j, a_m^{j-1}, \dots, a_m^{\frac{i+j+1}{2}}\right), \ \text{if } i+j \text{ is odd} \end{cases} \tag{11.9}$$

Filev and Yager [76] define the weight vector of OWA operators as given in Eqs. (11.10) and (11.11).

$$w_1^1 = \alpha_2, w_2^1 = \alpha_2(1-\alpha_2), \ldots, w_n^1 = \alpha_2(1-\alpha_2)^{n-2} \tag{11.10}$$

The second kind of weights $W^2 = \left(w_1^2, w_2^2, \ldots, w_n^2\right)$ is defined as:

$$w_1^2 = {\alpha_1}^{n-1}, w_2^2 = (1-\alpha_1){\alpha_1}^{n-2}, \ldots, w_n^2 = 1-\alpha_1, \tag{11.11}$$

The parameters are calculated as $\alpha_1 = \frac{g-(j-i)}{g-1}$, $\alpha_2 = \frac{(j-i)-1}{g-1}$, where g is the number of terms in the evaluation scale, j is the rank of highest evaluation, and i is the rank of lowest evaluation value.

Step 5 The geometric mean for each row ($\tilde{r}_i$) in $\tilde{C}$ is calculated as follows:

$$\tilde{r}_i = \left(\tilde{c}_{i1} \otimes \tilde{c}_{i2} \ldots \otimes \tilde{c}_{in}\right)^{1/n} \tag{11.12}$$

where $\tilde{c}_1 \otimes \tilde{c}_2$ is given as follows

$$\tilde{c}_1 \otimes \tilde{c}_2 = (c_{1l} \times c_{2l}, c_{1m1} \times c_{2m1}, c_{1m2} \times c_{2m2}, c_{1r} \times c_{2r}).$$

Step 6 The fuzzy weight ($\tilde{w}_i$) is calculated by using Eq. (11.13).

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\tilde{r}_1 \oplus \tilde{r}_2 \ldots \oplus \tilde{r}_n\right)^{-1} \tag{11.13}$$

where

$$\tilde{c}_1 \oplus \tilde{c}_2 = (c_{1l} + c_{2l}, c_{1m1} + c_{2m1}, c_{1m2} + c_{2m2}, c_{1r} + c_{2r}) \tag{11.14}$$

and

$$\frac{\tilde{c}_1}{\tilde{c}_2} = \left(\frac{c_{1l}}{c_{2r}}, \frac{c_{1m1}}{c_{2m2}}, \frac{c_{1m2}}{c_{2m1}}, \frac{c_{1r}}{c_{2l}}\right) \tag{11.15}$$

Step 7 The Steps 2–6 are repeated for each level of the decision-making model to find the weights of main-attributes, sub-attributes, and the alternatives.

Step 8 The fuzzy performance score of each alternative is calculated by Eq. (11.14)

$$\tilde{S}_i = \sum_{j=1}^{n} \tilde{w}_j \otimes \tilde{s}_j, \forall i. \tag{11.16}$$

where $\tilde{w}_j$ is the weight of the attribute j, and $\tilde{s}_j$ is the weight of alternatives with respect to attribute j.

Step 9 The fuzzy performance score of each alternative is compared with others using Eqs. (11.17), (11.18), (11.19), and (11.20) defined by [77].

$$\text{If } R(\tilde{c}_1) > R(\tilde{c}_2) \text{ then } \tilde{c}_1 > \tilde{c}_2 \text{ and} \tag{11.17}$$

$$\text{if } R(\tilde{c}_1) = R(\tilde{c}_2) \text{ then}$$

$$\text{If RM}(\tilde{c}_1) > \text{RM}(\tilde{c}_2) \text{ then } \tilde{c}_1 > \tilde{c}_2 \tag{11.18}$$

$$R(\tilde{c}) = \frac{(\tilde{c}_l + \tilde{c}_{m1} + \tilde{c}_{m2} + \tilde{c}_r)}{4} \tag{11.19}$$

$$\text{RM}(\tilde{c}) = \frac{(\tilde{c}_{m1} + \tilde{c}_{m2})}{2} \tag{11.20}$$

11.5 Gamification Based System Design

This section aims to present a numerical application proposed Hesitant Fuzzy AHP method on the design of a new gamification approach for the EDSM information system. Since there are various gamification elements, selection of the most appropriate combination is a very important decision-making problem. The problem can be modeled as an MCDM problem. To this end first the criteria for evaluating the alternatives are determined, then the alternatives are formed based on literature review and meetings with experts. Later, the steps of the methodology given in Sect. 11.4 are applied to select the best alternative.

The criteria considered in this study are determined as outputs. The main question is that how (positive or negative) and which the selected gamification elements affect users' energy-saving behavior. To this end, four criteria are determined to change users' energy consumption behavior by inspiring from [2].

- *C1: Structural interventions* aim the choices more attractive and may change perception and motivation of user.
- *C2: Informational strategies* increase individuals' awareness concerning impacts of their behaviors.
- *C3: Feedback* increases emphasis on individual-level, real-time, and interactive feedback.
- *C4: Social approaches* are used to know what others do to increase energy-saving behaviors.

On the other hand, the alternatives consist of different gamification approaches composed of different gamification elements. In the study, four alternatives are chosen from the literature summarized in Table 11.1. The four alternatives (Table 11.3) are shown. Therefore, the main question which is "how (positive or negative) and which the selected gamification elements affect users' energy-saving behavior" can be

Table 11.3 Alternatives (A) from literature

A1: Peham et al. [25]	A2: De Vries and Knol [22]	A3: Domínguez et al. [52]	A4: Gamberini et al. [23]
Leader boards	Levels	Badge	Feedback
Tips	Points	Feedbacks	Tips
Challenges	Rewards	Leaderboard	Social sharing
Levels	Social sharing	Reward	Challenges

Table 11.4 Pairwise comparison of the criteria with respect to goal

	C1	C2	C3	C4
C1	EE	Between EE and EHI	Between EHI and WHI	Between EHI and WHI
C2		EE	EHI	Between EHI and WHI
C3			EE	EE
C4				EE

Table 11.5 Trapezoidal fuzzy numbers associated with the expert evaluations

	C1	C2	C3	C4
C1	(1,1,1,1)	(1,1,1,3)	(1,1,3,5)	(1,1,3,5)
C2	(0.334,1,1,1)	(1,1,1,1)	(1,1,1,3)	(1,1,3,5)
C3	(0.2,0.334,1,1)	(0.33,1,1,1)	(1,1,1,1)	(1,1,1,1)
C4	(0.2,0.334,1,1)	(0.2,0.33,1,1)	(1,1,1,1)	(1,1,1,1)

answered easily. “Which” and “How” part of the question is obtained from Hesitant Fuzzy AHP and literature review, respectively. Also, it is important to obtain a meaningful result that any gamification element should not be included in all alternatives. If not, it is a neutral element and does not influence the result.

The decision makers fill the pairwise comparison matrices constructed with respect to the above-mentioned criteria and alternatives. Table 11.4 shows the pairwise comparison of the criteria with respect to the main goal.

Following the steps of the methodology, the HFLTSs are transformed into trapezoidal fuzzy numbers (Table 11.5).

For example, the value (1,1,1,3) in Table 11.5 is calculated as follows: The HFLTS associated with the evaluation is “Between EE and EHI” which involves triangular Fuzzy numbers (1,1,1) and (1,1,3). The parameters of the resulting fuzzy number (c_l, c_{m1}, c_{m2}, c_r) are obtained when we apply the operations in Step 4.

$$c_l = \min\{1, 1, 1, 1, 1, 3\} = 1 \tag{11.21}$$

$$c_r = \min\{1, 1, 1, 1, 1, 3\} = 3 \tag{11.22}$$

Since $i + 1 = j$,

$$c_{m1} = a_m^i = 1$$

$$c_{m2} = a_m^{i+1} = 1$$

when we apply Step 5 and 6, we obtain the geometric mean and fuzzy weights as given in Table 11.6.

The steps are repeated for all criteria, and the fuzzy weights of the alternatives with respect to each criterion are determined (Table 11.7).

As we multiply the alternative weights with respect to each criterion by the criterion weights, we can obtain the overall scores of each alternative with respect to the goal (Table 11.8).

The values given in Table 11.8 are summed up to find the total score of the alternatives. The total scores of the alternative are given in Table 11.9. To rank, the alternative Kumar et al.'s [77] ranking method, is used. The *R* and *RM* values are calculated (Table 11.9). The pairwise comparisons of alternative with respect to each criterion is given in Tables [11.10–11.13].

Based on the fuzzy ranking method described in Step 9, the alternatives are ranked as Alt2 > Alt3 > Alt4 > Alt 1.

Table 11.6 Geometric means and fuzzy weights

	Geometric mean	Fuzzy weights
C1	(1,1,1.73,2.94)	(0.145,0.198,0.519,1)
C2	(0.76,1,1.32,1.97)	(0.11,0.198,0.394,0.725)
C3	(0.51,0.76,1,1)	(0.074,0.151,0.3,0.368)
C4	(0.45,0.58,1,1)	(0.065,0.114,0.3,0.368)

Table 11.7 Fuzzy weights of the alternatives with respect to sub-criteria

	Weights w.r.t to C1	Weights w.r.t to C2	Weights w.r.t to C3	Weights w.r.t to C4
Alt 1	(0.06,0.13,0.29,0.59)	(0.05,0.10,0.15,0.31)	(0.05,0.09,0.19,0.52)	(0.08,0.17,0.20,0.36)
Alt 2	(0.13,0.25,0.57,1)	(0.05,0.13,0.15,0.24)	(0.04,0.09,0.13,0.3)	(0.15,0.29,0.45,1)
Alt 3	(0.10,0.19,0.38,0.78)	(0.10,0.20,0.30,0.61)	(0.10,0.24,0.42,1)	(0.08,0.17,0.26,0.36)
Alt 4	(0.04,0.08,0.29,0.40)	(0.23,0.44,0.56,1)	(0.12,0.31,0.64,1)	(0.11,0.22,0.26,0.62)

Table 11.8 Overall scores of the alternatives with respect to the goal

	Weights w.r.t to C1	Weights w.r.t to C2	Weights w.r.t to C3	Weights w.r.t to C4
Alt 1	(0.009,0.026,0.151,0.59)	(0.006,0.02,0.059,0.725)	(0.004,0.014,0.057,0.191)	(0.005,0.019,0.06,0.132)
Alt 2	(0.019,0.05,0.296,1)	(0.006,0.026,0.059,0.31)	(0.003,0.014,0.039,0.11)	(0.01,0.033,0.135,0.368)
Alt 3	(0.015,0.038,0.197,0.78)	(0.011,0.04,0.118,0.24)	(0.007,0.036,0.126,0.368)	(0.005,0.019,0.078,0.132)
Alt 4	(0.006,0.016,0.151,0.4)	(0.025,0.009,0.009,0.61)	(0.009,0.047,0.192,0.368)	(0.007,0.025,0.078,0.228)

Table 11.9 Total scores of alternatives

	Total scores of the alternatives	*R*-value	RM value
Alt 1	(0.024,0.079,0.327,1.638)	0.517	0.203
Alt 2	(0.038,0.123,0.529,1.788)	0.62	0.326
Alt 3	(0.038,0.133,0.519,1.52)	0.553	0.326
Alt 4	(0.047,0.097,0.43,1.606)	0.545	0.264

11.6 Conclusion

Supply and demand balance is very important for energy management. While supply management has been the focus traditionally, demand-side energy management has also become an important issue in recent years. As the technology develops, remote monitoring and control of electric devices have become possible. By utilizing gamification approach, these applications can be empowered. However, the design of a gamification empowered information system is not trivial. Since there are various gamification elements, there can be diversified gamification designs for the software. In this study, selection of gamification elements for demand-side energy management software is modeled as a multicriteria decision-making problem, after an extended literature review, alternative designs are prepared, and they are ranked using the Hesitant AHP method. For the further studies, other MCDM techniques can be used for the selection of the gamification elements and results can be compared with this study. Another branch of study can be formulated to show the effectiveness of the selected gamification elements.

Appendix

Table 11.10 HFLTS evaluations of the alternatives with respect to criterion 1

Verbal	Alt1	Alt2	Alt3	Alt4
Alt1	EE	Between ESLI and WLI	Between ELI and EE	Between EHI and WHI
Alt2		EE	EHI	Between EHI and WHI
Alt3			EE	Between EHI and WHI
Alt4				EE

Table 11.11 HFLTS evaluations of the alternatives with respect to criterion 2

Verbal	Alt1	Alt2	Alt3	Alt4
Alt1	EE	Between EE and EHI	Between WLI and ELI	Between VLI and ESLI
Alt2		EE	Between EE and EHI	Between WLI and ELI
Alt3			EE	Between ELI and EE
Alt4				EE

Table 11.12 HFLTS evaluations of the alternatives with respect to criterion 3

Verbal	Alt1	Alt2	Alt3	Alt4
Alt1	EE	Between EE and EHI	Between ESLI and WLI	Between WLI and ELI
Alt2		EE	ESLI	WLI
Alt3			EE	Between ESLI and WLI
Alt4				EE

Table 11.13 HFLTS evaluations of the alternatives with respect to criterion 4

Verbal	Alt1	Alt2	Alt3	Alt4
Alt1	EE	WLI	EE	Between ELI and EE
Alt2		EE	Between EHI and WHI	EHI
Alt3			EE	ELI
Alt4				EE

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Part III
Technology Innovation and Entrepreneurship

Introduction

Exploring the relations between the factors that led to different insights, Chaps. 12–16 facilitate recognition and planning the university's relationship between a country's economic power (GDP per capita) and its students' understanding of entrepreneurship/entrepreneurial feasibility. Additionally, the authors point out the importance of e-services and digital services adoption by college students and higher education, recognition technology like health IT, particularly Electronic Health Records. The last chapter features the case of high-tech startups applied to medical crutches and offers an example of technological assets and entrepreneurship as an investment, as well as sustainable development of the devices that users need with the examples of product features.

In Chap. 12 titled "Country Wealth Influencing University Students' Perceptions On Entrepreneurship Feasibility: A Survey," João Ricardo Lavoie, Marina Dabić, Tuğrul Daim, and Dara Shifrer identify and describe the relationship between a country's economic power (GDP per capita) and its university students' perceptions of entrepreneurship feasibility. The research is based on the linear regression models of the investigated data with 4455 students from nine European and Asian countries.

In Chap. 13 titled "Entrepreneurial University: Faculty's Previous Work Experience Predicting the Perceptions of Inadequate Link with Industry," Saeed Alzahrani, Marina Dabić, Tuğrul Daim, and Dara Shifrer determine the nature of the relationship between the faculty's previous work experience and the perception of the lack of links with the industry as an obstacle for the universities to become entrepreneurial. The authors examine the data on the university environment and culture toward entrepreneurial universities based on a particular Croatian university. This paper delivers a useful contribution to the literature, as it strives to detect that relationship in view of the impact of different factors.

In Chap. 14 entitled "First-Generation College Students and Satisfaction with Student-Success-Technology," Hans VanDerSchaaf and Dara Shifrer endeavored to examine how improving e-service distribution with relation to universities' goals can improve the undergraduate students' ascertainment and achievement for degree with the first-generation of undergraduate college students. Students' efforts on realizations are dire as the United States pursues to improve college completion by focusing on first-generation college students, whose rates of persistence and degree of attainment are significantly lower than their first-generation peers. The paper used the data from a survey of 701 Portland State University (PSU) students on the significance and satisfaction that students placed on bringing about essential tasks online.

Chapter 15 on "Assessing the Key Factors Impacting the Adoption and Use of Tethered Electronic Personal Health Records for Health Management," Saeed Alzahrani and Tuğrul Daim discussed Health IT, which includes well-recognized systems that have transformed the health sector such as Electronic Health Records (EHR), Electronic Medical Records (EMR), and Electronic Personal Health Records (ePHR). This chapter intends to examine the key factors impacting the adoption, and use of the tethered Electronic Personal Health Record (ePHR) to support patient-centered healthcare by permitting patients to access their health information from their provider's EHR. In the taxonomy created several vital factors play an essential role in the ePHR acceptance. The key elements are grouped into themes that include performance factors, effort factors, social factors, facilitating conditions, perceived credibility, health factors, and computer factors.

In Chap. 16 headed as "Design Study of Medical Device," Burcu Taşkın, Oya Akın, Husam Barham, and Nuri Başoğlu explore and recommend an approach for detecting design necessities for medical devices that address several competitiveness and innovativeness requirements of medical devices by using multiple techniques applied to humans and technology. This chapter focuses on medical crutches as an example by discovering the core problems of the existing crutches in the medical market. Then, the authors present a new crutch design in two phases: detecting crutch design requirements by design-based research, and describing market position including financial analysis.

Collaboration has been the key here and as such the shared ideas tended to contribute to the synergy that has resulted in a more thorough study. We bid you a heartfelt welcome to the network and invite your feedback and opinions. At the end of this exciting journey, we would like to thank the authors, the reviewers, and the publisher for their captivated support in embedding this book for the wide audience.

Chapter 12
Country Wealth Influencing University Students' Perceptions on Entrepreneurship Feasibility: A Survey

João Ricardo Lavoie, Marina Dabić, Tuğrul Daim, and Dara Shifrer

12.1 Introduction

Entrepreneurship studies have been attracting more attention in the last few years. Several articles provide a background and discuss the importance of entrepreneurship under a variety of circumstances, such as Ács et al. [1], van Stel et al. [2], and Intrama et al. [3]. University students of today are, undoubtedly, the leaders of tomorrow. Therefore, it is vital to understand their ideas, preferences, opinions, and perceptions in general, as to get a sense of what to expect from these future leaders and also to identify weaknesses and potential for improvements. Given the role both entrepreneurship and students play in our society, it is important to put those in context and to study them. Dabic et al. [4] have touched upon the convergence between students and entrepreneurship and this research is another building block to be added to the body of knowledge on the field—hoping to advance the understanding of our future leaders and how they perceive such a critical pillar of modern civilization. This study research question is:

- RQ: Is a country's Gross Domestic Product (henceforth referred to as GDP) per capita associated with university's students perceived feasibility of entrepreneurship?

This study makes use of a dataset generated by surveying students in nine European and Asian countries to delineate their perception of entrepreneurship in

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their countries. In addition, the economic power of each country is contrasted against its students' perceptions, in an attempt to identify a pattern. Existing literature linking students and their willingness and perceptions toward entrepreneurship have been focusing on factors such as gender and educational requirements, briefly dwelling on students' countries characteristics. This study, on the other hand, has primarily dealt with the proposed intersection between economic power and perceptions of entrepreneurship feasibility.

12.2 Literature Review

By analyzing entrepreneurship literature, one can easily realize that its importance is closely related to its correlation with economic growth. According to scholars, entrepreneurial activities tend to lead to higher and more intensive economic activity—as explained in the following paragraphs—and that would be entrepreneurship's greatest contribution to society.

Economic growth has been proven to enhance people's quality of life and minimize social tensions. Technology development and the creation of jobs, thus stimulating consumption, are closely related to generating economic growth, as briefly discussed in Ács et al. [1]. Brown and Mason [5] also argue that innovation and technology are important vectors of economic growth. Entrepreneurship, in turn, is said to help in the creation of jobs, technology development, and economic development. Intrama et al. [3] argue that there is a close relationship between creativity, entrepreneurship, and economic development. The authors state that "creativity and entrepreneurship are key success factors of creative economy-driven policy." Interestingly, when policies promoting entrepreneurship are put in place, investors tend to get higher returns and thus tend to invest even more in the region, creating a virtuous cycle that generates a more robust and resilient economy. A research piece was conducted and proved this point by investigating the interesting relationship between venture capitalists, angel investors, and entrepreneurship policies in China [6]. The researchers found that entrepreneurship policies would serve as guidance for investors and would influence their return on investments, especially when the amounts involved are high. Furthermore, van Stel et al. [2] found that entrepreneurship activity can produce a positive effect on economic growth. Therefore, it is important to understand the entrepreneurial spirit, in order to promote it and take advantage of it. More specifically, it is important to study and understand the way people regard entrepreneurship as an activity—its advantages, disadvantages, desirability, feasibility, and other aspects.

Richer countries have historically been associated with economic freedom and with easy and simple processes for its citizens to start their own businesses. Furthermore, rich countries' histories are intimately related to entrepreneurship in general [7]. Also, research has shown young people and university students are more prone to become entrepreneurs [8–10]. Schaeffer and Matt [11] investigated the role of academic institutions in promoting entrepreneurship, ultimately generating regional economic development. Therefore, for policy-makers who want to stimulate entrepreneurial spirit among its citizens, it is vital to focus their attention and efforts toward these groups. Dabic et al. [4] have also dealt with the entrepreneurship question among students. The researchers have used the Mann-Whitney nonparametric test to study gender differences in entrepreneurial intentions among university students.

The perceived feasibility and perceived desirability toward entrepreneurship have been related to factors such as gender, country, and educational requirements in previous studies [4, 12, 13]. Therefore, it seems logical to try to extend this work and correlate the Gross Domestic Product (GDP) per capita with the way its citizens perceive the entrepreneurship feasibility. Moreover, having in mind what has been found so far about university students and entrepreneurship, it would be very interesting to investigate how that segment of society regards the entrepreneurship feasibility in their countries. This leads to my hypothesis, as follows:

- h1: University students from countries with higher GDP's/capita will perceive entrepreneurship endeavors as more feasible.

This study also considers two extra variables in this context, namely student status and employment status. Student status depicts the extent to which the student dedicates him/herself to the studies. It is important to include this variable as a control in this study, since poorer countries might have more part-time students (because they may have to work to pay for their studies) and students that work may be more prone to become entrepreneurs, thus perceiving a higher feasibility in it. Employment status depicts the student's professional life. It is also important to include this variable as a control in this study, since poorer countries may have more "working" students, and also, the student's professional experience may influence the way he/she regards entrepreneurship (if the student already has its own business, it might perceive a higher feasibility in it). Including these control variables in models enables a less biased estimation of the relationship between country GDP and perceived feasibility of entrepreneurship. Hence, accounting for these extra factors enables the researcher to identify and explain any potential spurious relationships and its effects on the final model results. More information on the variables used is provided in the Method section.

The following figure demonstrates the relationships to be investigated in this research, in a graphical fashion (Fig. 12.1).

12.3 Data and Methods

Technology management researchers in Europe collected the dataset used to conduct this research. The topical focus of the dataset is entrepreneurship among university-level students. University students from nine European and Asian countries (Croatia,

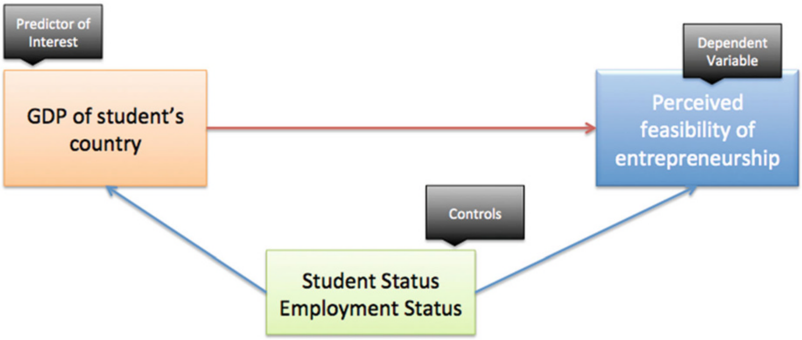

Fig. 12.1 Conceptual model of study

Austria, Belgium, France, Israel, Lithuania, Poland, Slovenia and India) were surveyed regarding a wide variety of aspects related to entrepreneurship, such as background information, future professional intentions, reasons why one would or would not start a business, questions related to the perception of entrepreneurship feasibility and desirability, previous work experiences, relatives' and family members' work experiences, the effects of their relatives' choices and experiences on their own career choices, and educational-related questions. In total, the dataset is comprised of 4455 cases. Since there were no missing values on the dependent variable, no cases were excluded and the analytic sample is comprised of the whole dataset, that is, 4455 cases. Missing values on independent variables were addressed with mean/mode imputation.

12.3.1 Dependent Variable

The dependent variable of this study is the perceived feasibility of entrepreneurship among university students in the nine studied countries. This variable was constructed from five other variables that, in an isolated fashion, aimed at measuring different aspects of the entrepreneurship feasibility, such as the perceived difficulty in starting a business, the level of certainty of success and failure, and the amount of knowledge and effort that should be put into such an endeavor. These five original variables were categorical ones, each of which had six categories measuring less or more perceived feasibility. The original variables were recoded to make sure all of them had the same directionality and were combined into a single feasibility index. The index was composed of the mean of the respondent's answers to the original variables—thus the final variable is a continuous one. Since the original variables had six categories, the resulting index ranges from 1 to 6–1 being the lowest perception of feasibility and 6 being the highest perception of feasibility. The Cronbach's alpha for the perceived entrepreneurship feasibility index is 0.544.

12.3.2 Predictor of Interest

The predictor of interest is the Gross Domestic Product (GDP) per capita of the respondent's country—this variable was not in the dataset. Once the information was collected from IECONOMICS INC [14], a variable was created and the values were assigned accordingly. As a last adjustment, the values were divided by 1000 so that the regression coefficients would not be impacted by the difference in scale of the studied variables—i.e., the range for the dependent variable is from 1 to 6, while the original range for the predictor of interest was from $1476 to $47,950. The adjusted values for the predictor of interest range from 1.48 to 47.95, as shown in the descriptive statistics table—enabling a more meaningful interpretation of the regression models results.

12.3.3 Controls

The control variables utilized in this study are student status (dichotomous variable where full-time students represent value 1 and part-time students represent value 0) and employment status (own a business; works for someone else; unemployed; retired). Because both control variables relate to the dependent variable and the predictor of interest, including these variables in the model improves the estimate of the relationship between students' country GDP per capita and students' perception of the feasibility of entrepreneurship (shielding the analysis from potential spuriousness).

12.3.4 Analytic Plan

At first, descriptive statistics are shown for all variables involved in the study. Then, linear regression models are estimated to analyze how students' country GDP per capita relates to students' perception of the entrepreneurship feasibility.

The first model shows the GDP per capita of the University student's country predicting his/her perception of entrepreneurship feasibility. The second model shows the same relationship, with the addition of student status and employment status as controls.

12.4 Results

12.4.1 Descriptive Statistics

Table 12.1 depicts the descriptive statistics. As already mentioned, the number of cases in this study is 4455. The range of GDP per capita is quite large, with India the lowest (US$1480.00) and Austria the highest (US$47,950.00). The average GDP per capita for the sample is US$22,670.00. After dividing these values by 1000, we have a range from 1.48 to 47.95, and the average is 22.67. The dependent variable (perceived feasibility of entrepreneurship), as discussed earlier, is an index ranging from 1 to 6. Values closer to one would mean a perception of lower feasibility, while values closer to six would mean a perception of higher feasibility. The value three would mean a neutral perception (neither positive nor negative). The average for the sample is slightly above three (3.23). Concerning the student status, the sample is mostly composed of full-time students, with only 12% part-time students. As for the employment status, the vast majority of respondents are in the workforce (82%)—22% have their own business and 60% work for someone else. Among the respondents who are out of the labor market, 12% are retired and 5% are currently unemployed.

12.4.2 Linear Regression

Table 12.2 depicts the results from linear regression models predicting the perceived entrepreneurship feasibility among university-level students. Results in the first model show that, on average, with every one-thousand-US-dollar increase in the

Table 12.1 Descriptive statistics

	Mean	SD	Range
GDP/capita of student's Country (div by 1k)	22.67	(13.16)	(1.48, 47.95)
Perceived feasibility of entrepreneurship	3.23	(0.68)	(1, 6)
Student status			
Full-time	0.88		(0, 1)
Part-time	0.12		(0, 1)
Employment status			
Has own business	0.22		(0, 1)
Works for someone else	0.60		(0, 1)
Currently unemployed	0.05		(0, 1)
Retired	0.12		(0, 1)
Students (*n*)	4455		

Note: GDP stands for gross domestic product

Table 12.2 Coefficients from regression models predicting the perceived feasibility of entrepreneurship

	Model 1	Model 2
	B (SE)	*B* (SE)
GDP/capita of Student's Country (div by 1k)	-0.01^{***} (0.00)	-0.01^{***} (0.00)
Student status		
Part-time (ref.)		–
Full-time		-0.12^{***} (0.03)
Employment status		
Has own business (ref.)		–
Works for someone else		-0.09^{***} (0.03)
Currently unemployed		-0.15^{***} (0.05)
Retired		-0.17^{**} (0.04)
Constant	3.36^{***} (0.02)	3.55^{***} (0.04)
R-squared	0.01	0.02

Note: Approximately 4455 students used to estimate each model
Note: GDP stands for gross domestic product
$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

country GDP per capita, student's perceptions of the feasibility of entrepreneurship decrease by 0.01 unit. The relationship between GDP per capita and perceived entrepreneurship feasibility is statistically significant ($p < 0.001$) but very weak. Strikingly, the influence is shown to be negative, contradicting my hypothesis. As opposed to what I hypothesized, the higher the GDP per capita, the lower the university-level student's perceived feasibility of entrepreneurship. Some possible explanations and recommendations for future studies are provided in the Sect. 12.5. Results from model 2 show that, on average, the perceived feasibility of entrepreneurship is 0.12 units lower for university students who work full-time relative to those who work part-time. As for the employment status, comparing against students who have their own businesses, those who work for someone else, on average, have a perceived entrepreneurship feasibility 0.09 units lower. Similarly, on average, those who are currently unemployed and retired have a perceived entrepreneurship feasibility of 0.15 and 0.17 units lower, respectively. All the observed relationships among the control variables are statistically significant, with p values being less than 0.001 ($p < 0.01$ for the "retired" category). Furthermore, the control variables do not alter the relationship between the predictor of interest and the dependent variable. The second model (net of controls) shows precisely the same relationship between the GDP per capita and the student's perception of entrepreneurship feasibility (on average, with every one-thousand-US-dollar increase in the country GDP per capita, student's perceptions of the feasibility of entrepreneurship decrease by 0.01 unit) and the relationship is still statistically significant ($p < 0.001$).

12.5 Conclusion

This study was conducted to identify and define the relationship between a country's economic power (GDP per capita) and its university-level students' perception of entrepreneurship feasibility. Data collected by surveying 4455 students in nine European and Asian countries was used and linear regression models were applied to analyze the data.

The research question asked if a country's GDP per capita is associated with university's students' perceived feasibility of entrepreneurship, and the hypothesis went on to assert that university students from countries with higher GDPs per capita perceive a higher feasibility in entrepreneurship endeavors. Nevertheless, results show that the hypothesis was clearly rejected—not only the relationship between these two variables is extremely weak, but the increased economic power of a nation seems to negatively affect its students' perceptions when it comes to entrepreneurship (the higher the GDP per capita, the lower the perceived entrepreneurship feasibility). One can think about possible explanations for this pattern. For instance, richer countries, given their superior economic performance, might be taking entrepreneurship for granted, thus not instructing its students about its strategic importance toward sustained economic development. Moreover, given the increase in the size of the state among European countries in the last few decades, excessive taxations and regulations might be gradually affecting the willingness of people to lean toward more risk-taking and challenging endeavors, such as starting a business.

The generalization of these research findings has to be done in a prudent and cautious fashion. The dataset used in this study was collected from university-level students in nine countries. However, the sample might not be representative because it is not certain that the sample represents, proportionately, the gender, age, and study area distribution in those countries, among other important factors. Furthermore, other countries might have a different academic setting and students with different mindsets. Having that in mind, it would not be prudent to extrapolate these results to other regions. In addition, although the study has made use of control variables to improve the linear regression estimates, the influence of unmeasured factors might also be considered a limitation.

Notwithstanding its limitations, this research piece improves the body of knowledge concerning entrepreneurship and has the potential to inform future researchers and policy-makers, aiming to further understand how students regard and understand entrepreneurship, ultimately leading to better policies. According to my findings, economic power is not positively associated with an increase in the perceived entrepreneurship feasibility. However, further studies should be conducted in order to validate these findings and explore other aspects related to the research question. Specifically, future study opportunities could look into how entrepreneurship instruction impact students' perceptions and inclinations toward entrepreneurship. Also, researchers could compare the amount of entrepreneurship-related courses and degrees offered in universities in both best-performing countries and worst-performing countries, as a means to delineate the potential dependency "entrepreneurship teaching and entrepreneurship action." Lastly, qualitative and quantitative studies could be conducted to analyze tax regulations, labor regulations, and entrepreneurship incentives in those countries.

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Chapter 13
Entrepreneurial University: Faculty's Previous Work Experience Predicting the Perceptions of Inadequate Link with Industry

Saeed Alzahrani, Marina Dabić, Tuğrul Daim, and Dara Shifrer

13.1 Introduction

The perceptions toward the barriers for universities becoming entrepreneurial are important to address. Investigating the relationships between the factors that lead to these perceptions helps understand and plan well for universities to become entrepreneurial. Studying the previous faculty work experience helps us examine the perception of inadequate link with industry as a barrier. This study uses data from a study conducted to examine the university environment and culture toward entrepreneurial university in a certain Croatian university. We aim to explore the relationship between the faculty's previous work experience and the perception of inadequate link with industry as a barrier for universities becoming entrepreneurial. This research provides a useful contribution to the literature, as it attempts to identify that relationship considering the impact of various factors. We found that there is less perception of inadequate link with industry as a barrier for faculty members who have experience in the private sector. The participation in a technology project, the perception of offering entrepreneurship courses for staff is a requirement for universities to become entrepreneurial, and the faculty's suitability to create their income factors are not explaining the relationship.

Research shows that the entrepreneurial university concept is becoming more prevalent over time. Universities play important role in creating jobs and participating in the economic growth. Also, they contribute to the technological

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advancements. Many authors have examined the concept of entrepreneurial university and proposed different definitions. Kirby et al. in 2011 [1] conducted a study to advance the existing literature regarding entrepreneurial university concept. The study aimed at identifying the most appropriate definition for the entrepreneurial university. Six definitions were identified from the literature to best represent the definition. Based on the raking of the suggested definitions by 221 experts in the entrepreneurship area, the experts considered the following two definitions as the most appropriate definitions for the entrepreneurial university concept:

> As at the heart of any entrepreneurial culture, Entrepreneurial Universities have the ability to innovate, recognize and create opportunities, work in teams, take risks and respond to challenges. Kirby [2]

> Just as the university trains individual students and sends them out into the world, the Entrepreneurial University is a natural incubator, providing support structures for teachers and students to initiate new ventures: intellectual, commercial and conjoint. Etzkowitz [3]

Etzkowitz and Dzisah [4] classify universities into three types based on their missions: teaching university, research university, and entrepreneurial university. The first one is the university that only teaches, the second one combines teaching with research, and the last one includes teaching, research, and entrepreneurial activities and services for society. The research indicates that MIT is the first university that included entrepreneurial activities to its existing conventional mission at that time which was teaching and researching [4]. This is considered the second academic revolution that emphasizes the economic and social development mission of the universities [4].

There have been various characteristics of the entrepreneurial university. A successful entrepreneurial university should have a combination of teaching, research, and entrepreneurial activities with many attributes within each one [1]. It is also the one that can innovate, collaborate, and contribute to the industry [1].

University-industry collaborations are an important factor in fostering the economic growth and creating a completive advantage. As a result, governments support the University-industry Knowledge transfer to foster the economic growth and support innovation [5].

University should build and maintain good partnership with the industry. Ankrah and AL-Tabbaa [6] conducted a systematic review to examine the Universities–industry collaboration. The study emphasizes five key aspects of the university-industry collaboration which can be considered the partnership lifecycle or the partnership process. University-industry partnership starts with specific motivation that derives the intention to involve or invest in such a relationship. It is then followed by the formation of the partnership phase which involves activities such as defining the relationship, preparing contacts, negotiating terms, and agreement signing. The third phase is the organizational forms which include one of the following activities: personal formal or informal relationships, and formal or none formal targeted agreements. The partnership then moves to the operational phase and comes to reality which involves activities such as meetings, communications, training, and employment. Other facilitating factors are considered in the operational phase. The last phase is the result of the partnerships that include benefits, some challenges, and lesson learned to both the university and the industry partner [6].

One goal of the entrepreneurial university is to be able to commercialize the intellectual knowledge of its members and put this knowledge to use. An interview study [7] was conducted with 18 researchers at Chalmers University of Technology, entrepreneurial university, to examine their views on how to commercialize their knowledge. The study suggests that both entrepreneurial university and government should consider alternative methods of commercialization of academic research outcomes such as the transfer of knowledge through firms established by the university alumni. It proposes a new concept of "need for utilization" to study the readiness of the researchers to transfer knowledge [7].

Many companies invest and fund research projects and university labs in order to maximize their share generated from research results [8]. In the health sector, for example, pharmaceutical companies invest in the development of new drugs in the universities' research labs [8]. Faculty members are now able with the support of their university to commercialize their inventions and discoveries and even capitalize on the economic potential of their research projects [8]. Between 1990 and 1995, one-third of the ventures were started with the help of a faculty member which represents the effort the universities are putting to be more entrepreneurial [8].

Kalar and Antoncic [9] conducted a study to examine the academics' perceptions of the concept of entrepreneurial university at four European universities. The study finds out that some department perceives themselves as more entrepreneurial than other departments within the same university and poses the entrepreneurial capabilities. This was due to their ability to conduct and engage in entrepreneurial activities. Academics with positive entrepreneurial perception are less likely to perceive the engagement in knowledge transfer can be harmful to academic science [9].

The university role has evolved beyond even being entrepreneurial to become the base for entrepreneurial society. A study examined the evolvement role of the university over time [10]. It suggests that it evolved over time due to the economic changes and entrepreneurship drivers. Economic has become knowledge driven rather than it used to be as a physical capital and then finally became an entrepreneurship driven. The new role focuses on enhancing entrepreneurship capital by providing thinking, leadership, and activity [10]. It dedicates serious attention toward the societal problems and challenges alongside the activities that facilitate the spillover of knowledge [10].

The public and private sectors are the two major sources of fund of the universities' research efforts. A report using data provided by the National Science Foundation indicated that federal funds had the lead in fueling research projects [11]. The recent statistics show that federal agencies provided only 44% of the spending on basic research in 2015 as compared to 70% on the 1960s. The pharmaceutical industry is fueling the increase in basic research investment by companies. The pharmaceutical industry fund increases from $3 billion in 2008 to $8.1 billion in 2014 on basic research [11]. Projects and research funds from the government and industry enable universities to maintain their mission as a major source of knowledge and inventions. These funds depend on the perceptions of the contribution it would make to the economy [12]. Universities pay a close attention to these perceptions by attracting industries to invest and fund researches by presenting their innovative outcomes and intellectual contributions [12].

The university-industry collaboration should be supported by the government as a main source of fund and regulations. Etzkowitz [13] proposed a "Triple Helix" model to mitigate the university-industry-government interaction as a core aspect of the entrepreneurial university mission. The Triple Helix model is a key driver of innovation in a society that is based on knowledge. Entrepreneurial University aims at transferring and putting the knowledge and technologies to use. Entrepreneurial university operates at interactive model of innovation. The entrepreneurial university falls in the intersection of these three important elements: university, industry, and government each of which has its unique role [13]. The university role is the creation of knowledge; government serves as public entrepreneur, regulator, and facilitator of this interaction; and industry is the main source of economic growth and application of the previous efforts. The interaction between these three entities promotes innovations and is used as a platform for new entrepreneurial university formation [13].

The triple helix model of innovation describes the knowledge transfer interaction [5]. Each dimension of the model generates specific benefits out of this collaboration. Fig. 13.1 shows the generated benefits for each of the collaboration partners [5].

Sarpong et al. [14] investigated the industry, university, and government organizing practices and how they facilitate the transition toward the triple helix model of innovation in the developing countries. The study tracked the evolving roles of the university, industry, and government in Malaysia toward the transition. The findings assume three main domains of practice that fosters the transition to a hybrid triple helix model of innovation which are sophisticated research competences, external relationships, and alliances; the quantification of scientific knowledge and output; and collective entrepreneurship activities [14].

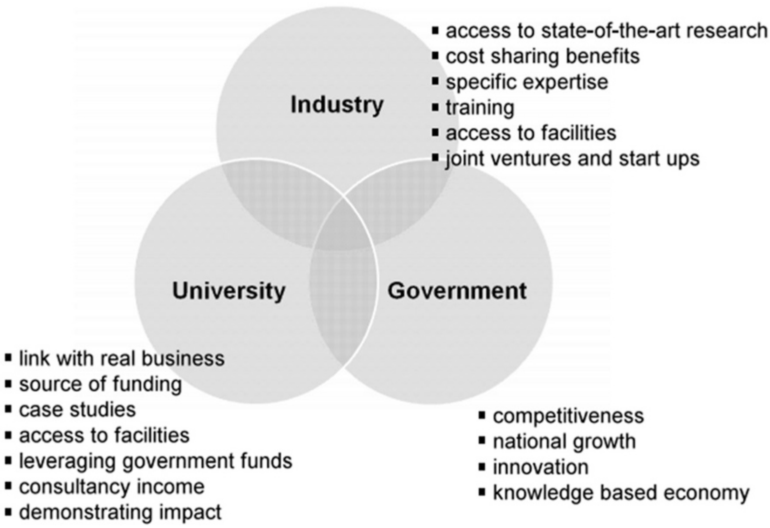

Fig. 13.1 The university-industry-government collaboration outcomes

As part of the process of improving the role of the universities toward entrepreneurship, many criteria are used to measure whether the universities are achieving that goal or not. Number of students in entrepreneurial program, number of courses, program, and activities of entrepreneurship, encouraging student attitude and values concerning entrepreneurship, course offering in entrepreneurship and research methodology, number of start-ups created, and employment and income generated are five important measurement factors [1].

Universities have an essential role in the development of knowledge-driven economies. The goal of the entrepreneurial university is to graduate students who can build businesses and create jobs. Universities are getting better in exposing their faculty members' intellectual contributions to the outside industry. Nowadays, most universities now have an office whose main job is to connect the university with the businesses.

This study aims to study, within the context of the entrepreneurial university, the relationship between faculty's previous work experience in the private sector and the perceptions toward inadequate link with industry as a barrier for universities to become entrepreneurial. Specifically, this study quantitatively analyzes the way in which these perceptions interact with the activities regarding faculties working in the private sector using data collected to investigate the university environment and culture toward entrepreneurial university. This study asks the following research question: Is there a relationship between previous experience in a private sector and faculty/staff's perceptions of inadequate links with business" as a barrier for university entrepreneurship?

Many activities are undertaken by universities to position themselves as entrepreneurial. Universities as well investigate the perceptions of their faculty and staff members about the factors that stand in the way of their universities to become entrepreneurial as well as the requirements to become entrepreneurial universities.

13.2 Literature Review

It is important to discuss the factors that are important for universities seeking to become more entrepreneurial as well as discussing the barriers that need to be addressed and resolved. Universities relationships with industries and businesses bring great benefits to the university itself and the development of the economies. However, it is a challenging task to bridge the gap between them. Building supportive educational environment to the entrepreneurship helps in transferring the university knowledge to the industry.

13.2.1 Technology Transfer Office (TTO) Role

A Technology Transfer Office (TTO) is established in many universities to help connect their faculty members' research and inventions with potential industry players [8]. The Technology Transfer Office is responsible for establishing and maintaining the relationship between universities and industry. The technology transfer office builds partnership between the universities and industry to enable: research partnerships and services, human resource transfer, commercialization of intellectual contributions, and scientific publications [15]. It serves as an intermediary role to facilitate the collaborations among different stakeholders [16]. Universities and industry partnerships result in R&D contracts as well [17]. Successful R&D contracts are influenced by the university and technology transfer office characteristics, and the university's location. Also, the economic factors influence the success rate of these partnerships [17].

Technology transfer offices should seek different ways to ensure successful university-industry collaboration. A study [18] suggests three informal technology transfer ways for faculty members to engage with industry: transfer of commercial technology, joint publications with industry scientists and R&D offices, and industrial consulting [18].

It is important to be able to value and recognize the university scientists' intellectual contributions and conduct appropriate technology transfer efforts to move their innovative ideas and patents to the industry. Some scientists and faculty members seek different activities to bypass their universities to privately sell or license their inventions. Markman et al. [19] studied the bypassing activities by the university scientists using data of 54 U.S. universities and 23,394 faculty members. The study finds that when appropriate technology licensing office efforts are undertaken and when the department receives greater shares of the royalties from the commercialization and licensing of their faculty members' inventions, bypassing activities by the university faculty and scientists is reduced. The study showed that 42% of the scientists who invent patents do bypass their universities [19].

13.2.2 Benefits and Motivations of the University-Industry Collaboration

A great amount of collaboration between the private sector and universities has been noted and proved its effectiveness. Identifying the benefits of the link with industry may facilitate the study of the importance of linking universities with industry.

D'Este and Perkmann [20] conducted a study on why academic engage in industry identified four motivations for faculty members to engage with industry. The first motivation is the ability for the faculty to commercialize their knowledge or technological inventions. Second, it gives the faculty the ability to learn from the industry new knowledge and best practices. Third, it allows access to research funds opportunities. Lastly, it enables them to take advantage of the industry in-kind resources such as new to the market equipment and real-life data [20].

Franco and Haase [21] summarized the previous literature on entrepreneurial university and identified the faculty member's motivations to seek funds from the industry. One main factor is the shortage in the public funding. They engage in researches funded by industry to have financing stream to their research equipment, laboratories, and students. This engagement, as well, results in providing the researcher with the real-life applications relevant to their research and helps in improving the quality of their research and teaching [21].

Other motivations for the researchers to seek industry collaboration include [21]:

– The ability to field-test practical application of their research outcomes.
– Gain access to state-of-the-art techniques, up-to-date equipment, and feedback from practice on research ideas and results.
– Gather new ideas for future research.
– Enhance the researcher's reputation and university's image.
– Complement their personal income.

The study as well conducted a case study in a university in Portugal [21]. It conducted interviews with university management. The result of the interviews aligns with the previous literature. It suggests that interviewees believe that interaction with industry increases academic reputation within the institution as the main motivator, the opportunity to apply research in the industry, to conduct research to be published in scientific journals, and to secure financial resources.

Bodas Freitas et al. [22] studied the university-industry engagement and cited the main motivations, objectives, barriers, or facilitators of the collaboration in the new industrialized countries. The study used data from interviews with 24 research group coordinators in science and engineering departments in PREOs in Brazil. These motivations include development and transfer of new knowledge and technology, access research grants and funds, and support the innovative capacity of the industry partner. The most common objectives cited in the study include: development of new product or process, improvement of product or process, and training of the company's employee [22].

13.2.3 The Barriers and Challenges of the University-Industry Collaboration

Despite the tremendous amount of benefits the collaborations between universities and businesses bring to the economies, there are various noted barriers and challenges that could prevent these partnerships from coming to life.

A survey of 221 experts in the entrepreneurship area on the university-industry collaboration barriers resulted in the ranking of the following barriers according to their impotence [1]: organizational structure and university governs, perception that entrepreneurship is not a primary function of the university, inadequate link with industry, the believe that collaboration not in concordance with research objectives, lack of experience, and inadequate cultural values [1].

Schofield [5] identified the following conflicts and barriers of collaboration: different time horizon, confidentiality where industry seeks secrecy of the inventions while the university seeks open source and publication, university research is driven by curiosity while industry research is problem solving driven, and cultural and organizational differences.

A study conducted interviews with university management in Portugal cited various challenges and obstacles of the university-industry collaboration from the perceptive of its faculty members: this kind of partnership is time and effort intensive, it is not yet a valuable indicator of performance compared to teaching and research, the existing workload forms a burden that slows the research productivity, and lack of organizational support [21].

Bodas Freitas et al. [22] studied the university-industry engagement barriers or facilitators of the collaboration in the new industrialized countries, the case of science and engineering departments in PREOs in Brazil. The barriers or facilitators of collaboration include location of the host university, tax incentives organizational support, ownership of the project, public research sponsoring, and time required by the company.

The common research practices depend on the publication of the new knowledge and that may interfere with the goals of collaboration from the industry side. Czarnitzkiet al. [23] conducted a study to investigate if the industry sponsorship jeopardizes disclosure of academic research using data from the OECD on German academic researchers. The findings confirm that industry sponsorship and funds jeopardize public disclosure of academic research. It shows a positive relationship between the degree of publication restrictions and secrecy and industry sponsorship. Also, it shows that researchers are willing to restrict disclosure in exchange for financial support by industry sponsors.

Conflict of interest may compromise the researcher's judgment in reporting research findings when the research is funded by private company. Darmon et al. [24] conducted a study to examine the previous literature on reporting the conflict of interest in the health care publications since it involves the quality of care provided to patients. Conflict of interest statements were indicated in 65% of the examined studies and 8% had declared conflict of interest which had been increasing over time. The study suggested a strong need for incentives to implement adequate reporting of conflict of interest.

The different interests on the university-industry relationship may result in ethical and economic challenges. A study [25] investigated the issues may raise due to the public and private funds of the schools of public health. The study suggests set of factors that should be considered when finding schools of public health: impact of the fund on the research orientations, some partners or funders are not suitable or acceptable, freedom limits due to the funds contracts, impact on the academic standards and ethics, impact on the knowledge of publication or secrecy, and effects on reputations that may result in bad partner selection.

Universities have a great deal of motivations to publish their research results very fast while businesses care about the secrecy of the information or at least delay of publishing the results in order to have competitive advantages over their competitors

[26]. Businesses look for fast commercial outcomes that have direct contributions to the core of their businesses from these partnerships [27]. The issues related to the intellectual property between universities and businesses may compromise the full utilization of the collaboration.

13.2.4 The Requirements to Build Entrepreneurial University

There is a set of factors that faculty members perceive and identify as requirements for universities becoming entrepreneurial.

A study [1] divided these essential factors in the development of the entrepreneurial university into formal and informal factors. The study found out that university faculty and staff members perceive link with industry, flexible organizational structure, entrepreneurship courses for students, support for technology transfer, and support measures for start-up as the most important formal factors for universities to become entrepreneurial. The informal factors that are perceived as essential are favorable staff attitude toward entrepreneurship, favorable student attitude toward entrepreneurship, and entrepreneurship role model [1]. Entrepreneurship education within the university is an important element of a successful entrepreneurial university.

In order to ensure successful knowledge transfer, certain steps should be considered [5]: creating better culture and awareness toward knowledge transfer initiatives, reducing resistance by providing training and education, and increasing a knowledge adoption level. Also, the development level of university partner is an important determinant of effective knowledge transfer and collaboration [5].

It is clear that entrepreneurship can be encouraged or advanced by the education and supportive environment. A study conducted to examine the entrepreneurial intention of university student found out that a supportive environment that provides adequate entrepreneurship knowledge and entrepreneurship spirit improves the possibility of graduating young entrepreneurs which shows the important role of the universities in improving the intention toward entrepreneurship [28].

Successful entrepreneurial university depends on experienced academic leadership, higher level of control over its direction and resources, organizational capacity to transfer knowledge, and entrepreneurial spirit [13, 29]. This would create sufficient autonomy required for universities to become an entrepreneurial [13]. Universities should seek to facilitate and provide the essential resources for themselves to be more entrepreneurial. These resources include building programs that are directed toward economic development activities [8]. Entrepreneurial university has the capabilities to make changes and evolve over time [30]. In the aim for transformation toward entrepreneurial, universities should seek: diversified funding base; strengthened steering core; developmental capabilities; encouraging academic destination; and solid entrepreneurial spirit [30].

Knowledge transfer capabilities are important indicator of the ability of the university to become entrepreneurial or to involve in a university-industry collaboration. Universities with their teaching, research, and knowledge transfer activities missions are significant drivers of the regional economic development and innovation distribution [31]. The university's dynamic capabilities influence its knowledge transfer capabilities [31]. A study [31] examined the knowledge transfer capabilities through the study of the ratio of published metrics to understand the collaboration between universities and industry and unpublished data on knowledge transfer performance. The results suggests that universitys' dynamic capabilities are significant indicators of successful knowledge transfer.

Another study which investigated the university's dynamic capabilities to drive competitiveness in the knowledge economy [32] suggests that university knowledge capabilities involve the university's ability to utilize its resources to transform opportunities in business success. These resources include the information and knowledge. These knowledge dynamics involves: socialization, externalization, combination, and internalization.

13.2.5 Industry Experience

The previous faculty members' work experience should enable strong understanding of the nature and environment of the industry. Several studies have investigated the university faculty industrial experience and its influence in teach and research. Also, executives and industry experts are now involved in the university as professors. A new concept of "professor of Practice" was introduced to represent the faculty members who are half time professor and the other half either business experts or entrepreneurs. Faculty internship is another way to enrich the existing faculty members' knowledge with the industry experience.

In the hospitality education, the previous industry experience is considered important. Phelan et al. [33] surveyed 175 hospitality faculty and students to study their perceptions of the importance of the faculty previous industry experience prior to teaching. The study results show that the recently hired faculty, in the past 5–10 years, have had limited relevant industry experience; the majority of the hospitality faculty members had previous experiences, mostly as managers or general managers; and few were reported not having worked in the industry. About 60% of the hospitality faculty members reported that instructors should have industry experience at the management level as they perceive the previous industry experience as an important indicator of effective teaching. The faculty members with previous industry experience indicated higher perceptions of the importance of the prior experience in the hospitality industry for the new hires. The findings suggest that faculty and student value the previous industry experience and its importance in teaching.

The previous work experience can have an impact on the faculty's commitment to teaching. One study [34] examined the influence of the faculty's previous industry work experience on their attitudes and behaviors toward teaching and research using data about engineering and natural sciences faculty members. The results show that faculty members with industrial experience are shown to have a positive and stronger commitment to teaching as they spend more time teaching, teach undergraduate courses, and are not interested in reducing their teaching workload in return for more time to spend on research. The study indicated the importance of the industry experience as an important criterion on the hiring decision.

A survey study [35] investigated how faculty members' characteristics, background, motivation, and the universities-industries collaboration influence the work outputs of the faculty members in Taiwan. The study indicates serval factors that have a significant influence on the universities-industries collaboration outcomes such as: previous work experience, universities, reputation and recognition, and the strength of social ties with the industry partner.

Richter and Loendorf [36] studied the advantages, reflections, and course enrichment that faculty with industrial experience bring into the classroom. The study is based on the authors' over 50 years of engineering experience perspective. The study emphasizes the importance of the previous industry experience in the classroom. Faculty with previous experience can utilize real-world problems and case studies to enhance the learning outcomes; combine the practice and theory perspectives into the educational process; and establish relationships with industry that can result in senior projects, internships opportunities, and job offers for students.

13.2.6 Professor of Practice

The "professor of the practice" (PoP) concept was introduced to achieve this mission (combining the teaching and research missions with the economic and social development missions) [4]. The professor of practice holds half time university professorship position and the other half as a business expert. The PoP role aims at blending the university way of teaching with the industry practices. The PoP should serve as a role model for the university faculty members planning to start their businesses or as link between the university and the industry [4]. It is believed that the university that utilizes the PoP model in order to link the university with the industry could achieve higher level of the academic development and societal engagement [4]. The PoP is a core element of the entrepreneurial university mission.

13.2.7 Faculty Internship

Different ideas have been introduced to bridge the gap between universities and industry. Faculty internships is one idea that aims at providing faculty members with opportunity to join the industry for a specific period of time to enrich their education skills, to incorporate new ideas into their teaching materials, and to receive firsthand experience. One study [37] looked at the business perspective of the faculty internship and noted positive opinions about the concept. Several benefit and concerns were reported. It would give the faculty the opportunity to gain access to fresh ideas in dynamic and fast evolving areas. Also, it allows for effective knowledge exchange between the universities and industry which would result in real-life business application in the classrooms. The concerns are time and money related as well as the value of the internship to the businesses [37].

Faculty Internship is an effective way to keep engineering faculty members connected with their fast-developing area especially the engineering technology programs as they combine the technical and engineering knowledge with the business practices. Nasab and Lorenz [38] introduced the Middle Tennessee State University (MTSU) experience with the faculty internship program and reported the advantages of the program. The internship at MTSU is supported by the industrial advisory council and allows one faculty member to leave his/her position at the university for one semester to join a local industry to work as an engineer. The study shows that the internship program contributes in the development of the faculty technological skills, builds relationship with local industry and technology experts, and understands of what the industry expects from the new graduates.

Another study [39] captured the perspective of engineering technology faculty members regarding the industrial internship conducted in a semiconductor incorporation. The industrial internship experience resulted in a development of new industry oriented course, update and improvement of the existing technology curriculum, lesson learned in the faculty internship implementation, facilitate the generation new of research ideas, and strengthen the university- industry partnership.

13.3 Conceptual Model

Participation in technology project and perception of entrepreneurship courses for staff as a requirement are important factors relating to the relationship between the previous work experience and the perception of inadequate link with industry as a barrier as my predictor of interest and dependent variable, and so may be spurious influences. I include these controls for these factors to achieve a less biased estimate of the relationship between faculty who have worked in a private sector and the likelihood that they perceive inadequate links to business as a barrier for their university becoming entrepreneurial.

Given the previous research on the perceptions of the faculty regarding inadequate link with industry as a barrier and the previous work experience in the private sector, I hypothesize that faculty/staff who worked in the private sector are more likely to perceive inadequate links with business as a barrier for university entrepreneurship than faculty/staff who did not work in the private sector (Fig. 13.2).

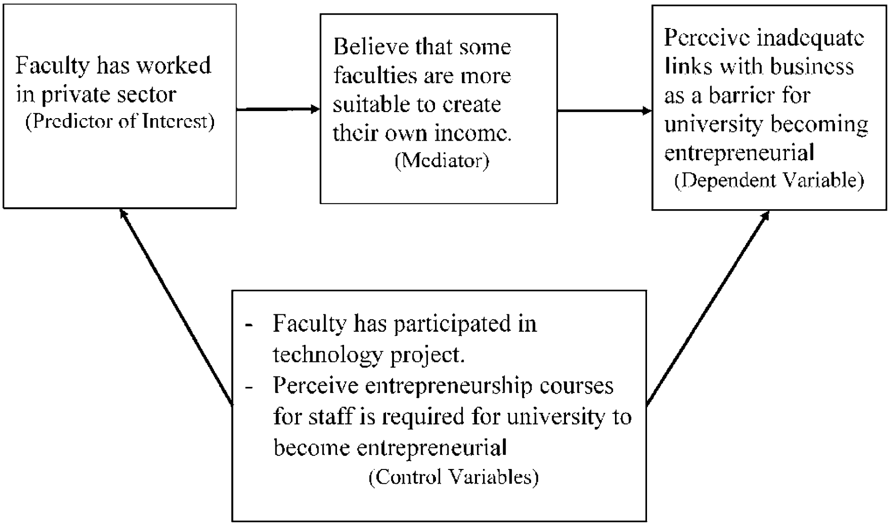

Fig. 13.2 Conceptual model

13.4 Data and Methods

This study used data collected by Dr. Marina Dabić in her research about the university environment and culture toward entrepreneurial university in a certain Croatian university. The date when the data was collected is unknown to this study. Respondents are university faculty and staff members with a sample size of 162 responses. The data collected is divided into four main sections. The first section looks at the faculty members' personal beliefs and attitudes toward entrepreneurial university including its definition, and barriers and requirement for universities to become entrepreneurial. The second part looks at respondents' opinion regarding the past situation in their university. The third part asks about the respondents' view of the current situation in their institutions. The final part looks at the personal characteristics of the respondents. No cases were excluded as none were missing on the dependent variable, resulting in an analytic sample of 162 individuals.

13.4.1 Dependent Variable

This study examines the extent to which a faculty member who has worked in the private sector perceives inadequate links between universities and outside industry as a barrier for universities to become entrepreneurial. The respondents rank this survey item from one ("not important") to five ("very important"). In order to create a dichotomous dependent variable, responses of four and five (important and very important) were combined into one category which is "one" that means "important."

Responses of one, two, and three were recoded as a zero which means "not important."

13.4.2 Predictor of Interest

This study's predictor of interest is whether the faculty member has worked in the private sector or not. The responses were 1 indicating the faculty has worked in the private sector and 0 for faculty who does not have an experience in the private sector.

13.4.3 Control Variables

Control variables included dichotomous measures of whether the faculty member has worked in a technology project and whether the faculty member perceives offering entrepreneurship courses for staff as required for universities to become entrepreneurial.

13.4.4 Mediator

To investigate one potential way the predictor of interest influences the dependent variable, respondents' belief that some faculties are more suitable to create their own income is used as a mediator variable.

13.4.5 Analytic Plan

Descriptive statistics for all variables used in the analysis are provided first. Logistic regression models are used to test whether respondent's perception of inadequate links between universities and the industry as a barrier for universities to become entrepreneurial differs depending on whether the faculty member has worked in the private sector or not. A first model shows the baseline relationship between the predictor of interest and the dependent variable. The second model includes controls for a more accurate estimate of this relationship. The third model includes the mediator variable in order to better understand the relationship between the predictor of interest and the dependent variable.

13.5 Results

Results from the descriptive statistics show that 78% of the respondents perceive inadequate links with industry as a barrier for universities to become entrepreneurial. Also, only 31% of the faculty members who participated in the study had worked in the private sector which emphasizes the real importance of linking the universities to the businesses. 89% of the respondents believe that some faculties are more suitable to create their own income. Universities conduct and participate in a lot of technology projects that when faculty members were asked if they have participated in them, only 28% responded by yes that they have participated. 75% of the faculty members perceive offering entrepreneurship courses for staff is a requirement for universities to become entrepreneurial (Table 13.1).

Table 13.2 shows odds ratios from logistic regression models predicting faculty members' perceptions on whether inadequate links with industry are a barrier for universities becoming entrepreneurial. Model 1 indicates that there is a marginally significant positive relationship between experience in the private sector and perceiving inadequate links between industry as a barrier for universities becoming

Table 13.1 Descriptive statistics

	Proportion
Perceives inadequate link with industry as a barrier for universities to become entrepreneurial (DV)	0.78
Has worked in the private sector (POI)	0.31
Has participated in technology project (Control)	0.28
Perceives offering entrepreneurship classes for staff is a requirement for universities being entrepreneurial (Control)	0.75
Believes some faculties are more suitable to create their own income (Mediator)	0.89

$N = 162$

Table 13.2 Odds ratios from logistic regression models predicting the perception of inadequate link with industry as a barrier for universities being entrepreneurial

	Model 1	Model 2	Model 3
	Exp(*B*) (SE)	Exp(*B*) (SE)	Exp(*B*) (SE)
Faculty member has worked in the private sector (POI)	0.51^{+} (0.40)	0.48^{+} (0.40)	0.43^{*} (0.42)
Faculty member has participated in technology project (Control)		0.72 (0.42)	0.78 (0.43)
Perception of offering entrepreneurship classes for faculty is a requirement for universities being entrepreneurial (Control)		2.30^{*} (0.42)	2.05^{+} (0.43)
Perception of some faculties are more suitable to create their own income (Mediator)			1.95 (0.60)

$N = 162$ respondents
$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

entrepreneurial ($p < 0.10$). On average, the odds of the perceiving inadequate link with industry as a barrier for universities becoming entrepreneurial is 49% lower on average for faculty who has worked in the private sector than the odds for faculty who does not have an experience in the private sector.

The second model includes faculty participation in technology project and the perception of offering entrepreneurship courses for staff is a requirement for universities to become entrepreneurial as controls. On average, the odds of perceiving inadequate link with industry as a barrier for universities becoming entrepreneurial is 28% lower on average for faculty who has participated in technology project than the odds for faculty who have not participated in a technology project. The relationship is not statistically significant. Also, on average, the odds of the perceiving inadequate link with industry as a barrier for universities becoming entrepreneurial is 130% higher for faculty who perceive offering entrepreneurship courses for staff is a requirement for universities to become entrepreneurial than the odds for faculty who does not perceive offering entrepreneurship courses for staff is a requirement for universities to become entrepreneurial. The relationship is statistically significant ($p < 0.05$). Accounting for the potentially relevant differences across faculty members, the relationship remains marginally significant, with the odds that the faculty member perceives inadequate links between industry as a barrier for universities becoming entrepreneurial 52% higher for faculty with experience in the private sector relative to faculty with no experience in the private sector. The third model added a mediator trying to see if the faculties who have worked in the private sector are more likely to perceive certain faculty as more suitable to create their own income, which is partially why they are more likely to perceive the university's inadequate links with industry as a barrier.

Model three considers the same control variables in the second model beside the mediator. For the control variable, on average, the odds of the perceiving inadequate link with industry as a barrier for universities becoming entrepreneurial is 22% lower for faculty who has participated in technology project than the odds for faculty who does not have experience in the private sector. The relationship is not statistically significant. Also, on average, the odds of the perceiving inadequate link with industry as a barrier for universities becoming entrepreneurial is 105% higher for faculty who perceive offering entrepreneurship courses for staff is a requirement for universities to become entrepreneurial than the odds for faculty who does not perceive offering entrepreneurship courses for staff is a requirement for universities to become entrepreneurial. The relationship is marginally significant ($p < 0.05$).

For the mediator, on average, the odds of the perceiving inadequate link with industry as a barrier for universities becoming entrepreneurial is 95% higher for faculty members who believe many faculties are more suitable to create their own income than the odds for faculty members who think all faculty can create their own income. The relationship is not statistically significant.

Overall, it appears that the relationship between the perception toward inadequate link with industry as a barrier for universities becoming entrepreneurial and the faculty members having experience in the private sector becomes statistically significant ($p < 0.05$). The model shows that there is less perception of inadequate link with industry as a barrier for faculty who has experience in the private sector. Thus, the odds ratio shows an increase from the second and third models in explaining the relationship between the perception toward the inadequate link with industry as a barrier for universities becoming entrepreneurial with a 57% lower for previous work experience affecting the perceptions toward the link with industry. The model shows that the variable suspected to be a mediator is, in fact, not a good mediator because the odd ratio has increased while it should have been decreasing to better explain the relationship.

13.6 Conclusion

The purpose of this study is to understand the relationship between the faculty's previous work experience and the perception of inadequate link with industry as a barrier for universities to becoming entrepreneurial using data from a study about the university environment and culture toward entrepreneurial university in a certain Croatian university.

The finding of this study shows that there is less perception of inadequate link with industry as a barrier for faculty who has experience in the private sector. The participation in a technology project, the perception of offering entrepreneurship courses for staff is a requirement for universities to become entrepreneurial, and the faculty suitability to create their income factors are not explaining the relationship. The hypotheses suggested that there is a higher perception toward inadequate link with industry as a barrier for universities to become entrepreneurial for faculty with previous work experience in the private sector. However, the analysis has proven that there is less perception of inadequate link with industry. That might be because the faculty members with previous work experience in the private sector may not need the university link with industry since they already have established connection with industry, while the faculty members without experience in the private sector may find it challenging to connect with the industry and find their universities not supporting the link with the industry. More involvement of the faculty members with previous work experience in the private sector is required from the universities in order for a better understanding of their perceptions. Also, universities seeking to become entrepreneurial should facilitate the connections and partnerships with the private sector.

The limitation of the study is that the control variables and the mediator are not actually measuring the relationship between the previous work experience in the private sector and the perception toward inadequate link with industry as a barrier. Adding more variables to the models could provide a better understanding of the relationship.

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Chapter 14
First-Generation College Students and Satisfaction with Student-Success-Technology

Hans VanDer Schaaf and Dara Shifrer

14.1 Introduction

In today's digital age, fueled by consumers' expectations for robust and personalized digital experiences, the adoption and use of electronic services (e-services) by customers and constituents is critical. In higher education there is an immense need for institutions to build service and digital experiences that match what students experience in their broader lives. In parallel, public universities are under tremendous budgetary and performance pressure from the general public and state legislators to increase graduation rates while living up to their goals for improving access to higher education. Central to their efforts is a focus on assisting first-generation college students graduate, as they are less likely to persist after their first year and less likely to graduate, compared to their non-first-generation peers [1–3]. One tool in these efforts is technology that students can use to support their own continued enrollment, and technology for faculty and staff to use to support student success—commonly referred to as student success technology (or student-success-technology). In the context of recent critiques of higher education, including demands to lower costs, deliver a more educational value, and provide an educated workforce to meet economic demands, this work is critically important [4].

This study seeks to contribute to knowledge at the intersection of e-services/digital services adoption by college students and higher education sector strategies about how to most effectively leverage technology to improve student success generally, and the success of first-generation college students in particular. In this vein, it investigates the following questions: How does first-generation college student status relate to satisfaction with student-success-technology? Does gender

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moderate this relationship? We hypothesize (H1) that because first-generation students have less familiarity with college and experience more barriers in accessing it, they might be more satisfied with student-success-technology than their non-first-generation peers, as in many ways this technology is designed to help reduce barriers to succeeding in college. Further, given that technology adoption and people's experiences with technology can be influenced by gender, we hypothesize (H2) that for first-generation college students there will be differences in satisfaction with student-success-technology by gender.

The study uses data from a survey of Portland State University (PSU) students about the importance and satisfaction that students placed on accomplishing key tasks online through the myPSU website (my.pdx.edu) and PSU digital services (both are technology platforms for Portland State students). The survey was administered under the reTHINK PSU initiative in May 2016 and has an analytic sample of undergraduates ($n = 701$ respondents).

While limited, the literature on student-success-technology and first-generation students—"undergraduate students whose parents had not participated in postsecondary education" [1]—shows that student-success-technology plays an increasingly vital role in the delivery of services. Students rely on self-service digital tools to conduct university-related business and that access to such tools can be particularly important for nontraditional students, many of whom are first-generation. The dialogue about e-services sits within massive efforts across the United States to improve student success. First-generation students experience significant barriers to accessing higher education, including basic knowledge about higher education, access to resources to cover tuition and fees, family guilt (i.e., guilt they may experience as a result of feelings that they are abandoning their families by attending college), and institutional cultures that could be much more supportive [2, 5–7]. Very little research exists about first-generation college students and their relationship with student-success-technology, including no research we could find about satisfaction with student-success-technology. However, a very limited body of related research suggests that there could be a relationship between first-generation status and technology generally, and specifically a relationship with student-success-technology, that can help remove barriers. This study will contribute to the literature by providing findings specifically about first-generation students and student-success-technology, in an effort to aid universities and others with enhancing knowledge about how best to serve these students.

14.2 Literature Review

The primary goal of this study is to understand if there could be a relationship between satisfaction with student-success-technology and first-generation college student status, and whether this relationship might be moderated by gender. In this section, we summarize research about these topics in order to articulate how our research questions build on existing literature. This study sits in the context of an increasing reliance on e-services in higher education. We first summarize the literature on this topic.

14.2.1 E-Services in Higher Education

Technology plays an important role in our lives today, including the lives of university students and their institutions. Universities are not immune from the changing landscape of consumer/student expectations, where services are expected to be digital, efficient, and seamless. Services now account for a large part of economies around the world, including in the United States [8], and consumers are well adept at online purchases including through smartphones [9]. Further, consumers expect that organizations are focused on the quality of the "entire customer experience" [10].

Technology is increasingly involved in the delivery of services, which are "deeds, processes and performances...provided to customers in exchange relationships among organizations and individuals" [11]. We define e-services in a higher education context—drawing from definitions of e-services in the public sector literature [12], e-commerce literature [13], and higher education [14, 15]—to be information and communication technologies to enable web-based service delivery that seamlessly brings together distributed resources to enable complex transactions. E-services provide higher education institutions with the ability to improve the efficiency and effectiveness with which services are provided to students, employees, the public, community partners, and other stakeholders. A subset of e-services is called administrative e-services, which are e-services that students use when accomplishing tasks related to maintaining their enrollment and student support services. They include scheduling advising appointments, paying bills, registering for courses, degree audit, transcripts, applying for financial aid, signing up for campus clubs, finding on-campus parking, applying for scholarships, applying for admission, and accessing academic supports [16, 17].

Students services, including those that are online, play a critical role in a university. They can affect the financial and learning bottom lines [14, 17]. For online students, the quality of services can have a profound influence on their experience and learning [18]. For "nontraditional" students (e.g., those who are enrolled part-time, working while enrolled, and/or have families; they are increasingly the new "traditional" student), access to online services can be particularly important so they can study while on breaks from work or find help outside of traditional business hours [19]. The delivery mechanisms for services are increasingly mobile [20] and challenged by universities' legacy systems [19]. Higher education faces a clear and challenging mandate to change to this new paradigm of service [21]. Changes can make a profound difference for the estimated 20.4 million students enrolled in postsecondary institutions in the United States [22].

14.2.2 Student-Success-Technology

Student-success-technology (often referred to as Integrated Planning and Advising for Student Success [iPASS] systems) is a large subset of administrative e-services and is related to supporting undergraduates with persisting and ultimately graduating from college [23]. Student-success-technology is positioned to substantially enhance efforts to improve student success, as the locus of change for improving student success has moved from faulting individuals to looking at the environments that higher education institutions create. While several decades ago, student retention was viewed as a reflection on individuals' skills and motivations, this view has changed substantially, where today, research widely recognizes that "the role of the environment, in particular the institution, [is critical] in student decisions to stay or leave" [24]. Increasingly, the role of the institution also involves their digital services.

As a critical part of the institutional environment and in some ways a manifestation of a university's culture, student-success-technology can help play a critical role in addressing barriers college students face. Student-success-technology focuses on providing real-time and proactive support for students, such as communication campaigns delivered via email, SMS for coaching and advising, and mobile app notifications to support students in completing critical administrative tasks, such as resolving account holds that prevent registration. Student-success-technology can include the following: degree audit tools; degree planning or mapping tools; online self-service tools for student business; early-alert systems to catch academic troubles; and "digital tools that keep a record of services used, advice given, or decisions made" [4]. An emerging focus of student-success-technology is the use of predictive analytics, which are noticeably more present in advising services, yet still relatively new [25]. Predictive analytics enable more timely and customized service delivery, such as helping students better plan their courses, enhancing recruiting and retention efforts [26], as well as enabling targeted outreach and interventions by advisors [25].

14.2.3 Student Success Goals

Dialogue about student-success-technology sits within massive efforts across the United States to improve college graduation rates. At the same time that demand is increasing for workers with a college degree [27], large numbers of Americans do not possess this credential. The Lumina Foundation reports that "The share of Americans with degrees and post-high school credentials is now at just under 47%, up one percentage point from a year earlier. At the same time, disparities in attainment across racial/ethnic groups remain, threatening prospects for continued improvement of overall attainment levels" [28]. Additionally, undergraduate departure and graduation rates are still abysmally low. Between 1983 and 2010 "approximately 28% of first-year students enrolled in 4-year colleges and universities depart at the end of their first year" [29] and only a little more than half of undergraduate college students complete their postsecondary degrees within 6 years [30]. This focus on student success relates to who are today's college students: 61% receive Pell grants (Federal grants for students with financial need); 26% are employed full-time; 42% are students of color; 73% take classes in the classroom only; and 47% are 22 years of age or older [31].

14.2.4 First-Generation College Students

At the heart of universities' goals to improve student success are efforts to support undergraduate first-generation college students (FGCS). It is important to understand the barriers they face in order to inform the first part of this study's H1: "…first-generation students have less familiarity with college and experience more barriers in accessing it." Although there are several definitions of first-generation college students [32], for this study we define them as "undergraduate students whose parents had not participated in postsecondary education" [1]. First-generation students are a sizable number, although their proportions have decreased over time, from 1999 to 2000 when the proportion was 37% to 2011–2012 when the proportion was 33% [1].

FGCS face unique challenges in enrolling in and completing college as compared to their peers who have family members who attended college or earned a bachelor's degree. "Three years after first enrolling, comparatively more first-generation students who began postsecondary education in 2003–04 had left postsecondary education without earning a postsecondary credential (33%) than had their continuing-generation peers whose parents attended some college (26%) and whose parents earned a bachelor's degree (14%)" [1].

The majority of FGCS have low socio-economic backgrounds [33], which creates financial pressure in their college experiences. As a result, these students are more concerned about finances and they are employed more—both of which tend to have negative impacts on persistence and the time available for studying and other college-related activities [3]. FGCS also experience a lack of cultural capital that prepares them to navigate college life: basic knowledge about higher education, such as information about the application process, how to understand the costs, and how best to choose colleges, puts them at a disadvantage even before setting foot on college campuses [2]. Additionally, they are often unsure of the benefits of attending college [2] and at times are not encouraged to attend [34], in contrast to traditional students, who are often expected to attend college from an early age [34, 35]. This cultural deficit is realized in the classroom as well, where traditional students are better equipped to understand and respond to professors' expectations [6] and where FGCS with higher perceptions of college self-efficacy (confidence in tasks associated with college) are more likely to have higher perceived progress in achieving academic goals [36].

When they arrive at college, FGCS are often met with institutional cultures and environments that could be much more supportive [7]. Recent research highlights that institutions have a critical role in supporting FGCS, rather than attributing a lack of educational outcomes to student shortcomings [37]. The framing of many institutions tends to focus on individual achievements, which can be in stark contrast to the collectivist frame that many first-generation Latino students exhibit [38]. For example, inflexible institutional policies and procedures around costs can create real challenges for FGCS [37]. In addition to barriers faced in school itself, family achievement guilt, whereby FGCS "experience a discrepancy between the opportunities available to them and those available to their non-college-educated family members" [39], can negatively impact academic performance [3]. The above barriers impact FGCS success in college. Researchers consistently find that FGCS are more likely to leave a 4-year institution at the end of their first year, compared to their traditional counterparts, and are less likely to graduate [1–3]. Further, students who experience lower academic self-efficacy, including FGCS [3], maintain a lower grade point average [40].

14.2.5 First-Generation College Students and Their Experiences with Technology

In order to inform the second part of H1—first-generation students "might be more satisfied with student-success-technology than their non-first-generation peers, as in many ways this technology is designed to help reduce barriers to succeeding in college"—it is important to understand how FGCS relate to technology. However, there is only one study we could find on this topic. As such, we first discuss this study and then draw from data on college students as a whole and digital divide research about students and technology.

The most relevant research about FGCS and student-success-technology comes from a survey conducted by EDUCAUSE, called the "ECAR Study of Undergraduate Students and Information Technology, 2017" which summarizes the responses from 35,760 undergraduates from 110 U.S. institutions [4]. The survey describes that for most students, "student success technologies are seen as useful because they mitigate or moderate some of the things that make being a student difficult. That said, these technologies are more useful to some students than to others. Specifically, students who may possess structural (e.g., ethnicity, gender), socioeconomic (e.g., class), or other circumstantial (e.g., first-generation college student) disadvantages find student success tools more useful than students more advantaged in these areas." Further, the study found that "first-generation and black or Hispanic students find all of the student success tools—except degree audit and planning tools—to be more useful than non-first-generation and white students" [4]. A possible counterpoint to the ECAR survey is that a survey of 226 Hispanic college freshmen about educational uses of internet sites found that there were no differences between first-generation college students and non-first-generation college students [41]. Slate et al. find this puzzling "because higher educational levels among the general population have been a strong determinant of increases in computer ownership and Internet use" [41].

Turning to broader data on college students to inform this study, the far majority of twenty-first century students are comfortable with technology and are markedly more adept at accessing the Internet and its services than older adults [42]. Correspondingly, students are more and more comfortable learning at a distance—growth rates in online student enrollment have been significantly higher than the overall growth in higher education [43]. Drawing again from the ECAR survey on students and technology, today's U.S. undergraduate students' ownership of technology continues to grow. From 2015 to 2017, smartphone ownership increased from 92% to 97% and laptop ownership rose from 91% to 95%. In addition, almost all students own a laptop or a smartphone [4, 44]. Further, students own more devices, proportionally, than the general public—more than half of students own a laptop, a tablet, and a smartphone, compared with only a third of the American public [44].

Additional research adds texture to these trends, showing for example that university students demonstrate positive attitudes about using the Internet and that they view it as a functional tool to support their learning [45]. Also, students expect their institutions to have digital services comparable to what they experience in their personal lives [46]. A 2016 survey by DJS Research of more than 2000 students across the world, including those in the United States, found that nearly one-third of respondents in the U.S. "think less of their institutions because of their digital strategies" [47].

While we could not find research specifically about satisfaction with student-success-technology, a limited body of digital divide ("gap between those who have and do not have access to computers and the Internet" [48]) research suggests that one might expect differences in subgroups of students [49]. Hargittai's study of first-year college students found that higher levels of parental education are associated with higher levels of use of the Internet and that "socioeconomic status is an important predictor of how people are incorporating the Web into their everyday lives with those from more privileged backgrounds using it in more informed ways for a larger number of activities" [50]. Not surprisingly, there is a relationship between students' families' household incomes and cell phone ownership—students from wealthier families are more likely to own cell phones [49]. Research about computer literacy differences between nontraditional college students (many of whom are first-generation) and traditional students finds that traditional students tend to have more expansive computer knowledge [51].

Building off of the research described in this section, following is H1:

(H1) Because first-generation students have less familiarity with college and experience more barriers in accessing it, they might be more satisfied with student-success-technology than their non-first-generation peers, as in many ways this technology is designed to help reduce barriers to succeeding in college.

In summary, this related research suggests that there could be a relationship between first-generation status and technology generally, perhaps extending to student-success-technology, and that having technology knowledge is a precursor to college success [52].

14.2.6 Gender and Technology

Based on a review of the technology adoption literature related to gender, it is possible that males and females might derive differing levels of satisfaction from student-success-technology, suggesting that gender might moderate the relationship between first-generation status and satisfaction. For example, [53] found that gender can play a moderating role in relation to technology adoption, [54] report that there can be differences in gender in relation to innovating with technology, and that men and women are differently influenced by their own attitudes about technology when adopting it [55]. Additionally, there can be differences in the pace with which men and women move through the technology adoption cycle [56]. Thus, oursecond hypothesis (Fig. 14.1).

(H2) For first-generation college students there will be differences in satisfaction with student-success-technology by gender.

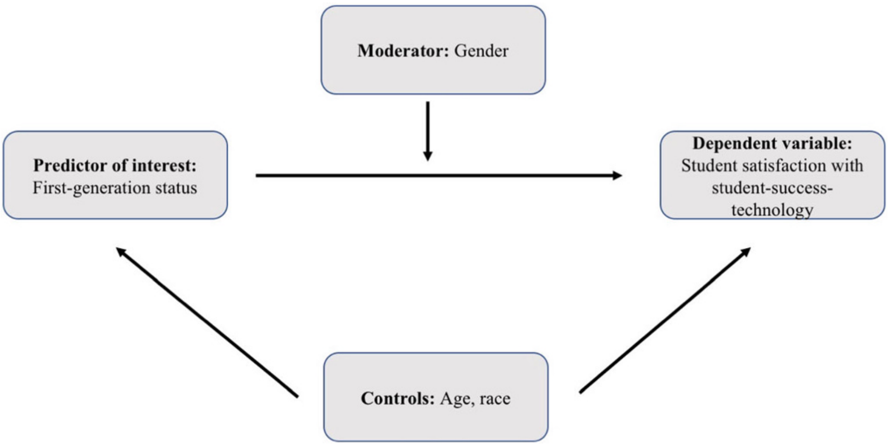

Fig. 14.1 Conceptual model

14.3 Selection Bias

Accounting for selection bias will be critical in this research. A person's age [53, 57–59] and race [60, 61] might influence how they perceive and use technology. It will be important to control for these potentially spurious influences.

14.4 Data and Methods

14.4.1 Data

The data used in this study is from the Redesign myPSU student survey, which was administered to understand the importance and satisfaction that Portland State University (PSU) students placed on accomplishing key tasks online through the myPSU website and PSU digital services, such as applying for scholarships, easily identifying and purchasing books and course materials, and quickly finding classes using an online map. Distributed by Portland State University's Office of Academic Affairs with assistance from the Portland State Survey Research Lab, the survey was emailed to a randomly generated list of 8500 Portland State University students (undergraduates, graduates, post-baccalaureate) on May 26, 2016 and remained open through May 31, 2016. The sample size is 1190 respondents.

This study focuses on respondents who were undergraduates ($n = 821$; 369 fewer cases than the entire sample) at the time of the survey per PSU records, as they are the population where there is a significant national focus for improving graduation rates. The analytic sample for this study excludes cases who were missing on more than 40% of the 17 variables that were combined to create the dependent variable, satisfaction-with-student-success-technology. Mean/mode imputation was used to address missing values on all independent variables.

14.4.2 Dependent Variable

This study examines differences by first-generation status in relation to undergraduate students' satisfaction with student-success-technology. We created a scale to measure satisfaction-with-student-success-technology by combining 17 survey items about satisfaction with completing administrative/non-academic online tasks or accessing online resources (see Appendix for the original survey items, Cronbach's alpha = 0.71). Respondents were asked to rate their satisfaction with each of the 17 items on a Likert-type scale ranging from 1 to 5, with 1 = Very Dissatisfied and 5 = Very Satisfied. The 17 online tasks were identified through several in-person engagement sessions/focus groups with students, where the PSU project team worked to distill the most critical tasks students wanted to accomplish online. To create the scale itself, we calculated the means across the 17 tasks for each case and then recoded any cases that were missing more than 40% of answers to the original 17 items as missing.

14.4.3 Predictor of Interest

The predictor of interest in this study is first-generation status. This is a dichotomous variable indicating whether a respondent self-reported on PSU's admissions application as a first-generation college student, with 1 indicating the respondent was a first-generation college student and 0 indicating they were not. There were no missing values for this variable.

14.4.4 Moderator

The moderator in this study is gender, as it is possible that this variable affects the strength of the relationship between a student's first-generation-status and satisfaction with student-success-technology. This is a dichotomous variable where 1 indicates male and 0 indicates female. There were no missing values for this variable.

14.4.5 Controls

The controls are age and race, as our review of the literature indicated they relate both to being a first-generation status and to student-success-technology. Mean imputation was used to address missing values for age. Mode imputation was used to address missing values for race. Race was then recoded from a categorical variable with eight categories to three dichotomous variables—White, Hispanic or Latino, and Other—to aid with analysis. By using these controls, the study will be able to improve estimates for the predictor of interest—reducing bias related to spuriousness (i.e., alternative explanations).

14.4.6 Analytic Plan

Descriptive statistics are used to describe all variables used in analysis and detect baseline differences among the analytic sample.

Linear regression models show how satisfaction with student-success-technology depends on an undergraduate student's first-generation status. The first model focuses on the baseline relationship between an undergraduate student's first-generation status and their satisfaction with student-success-technology, while the second model includes all controls discussed in the previous section. Each of these models is estimated separately for males and females to understand whether gender moderates the relationship.

14.5 Results

Table 14.1 provides descriptive statistics by gender. Overall, sampled students' qualities are quite consistent across males and females. The mean satisfaction with student-success-technology is slightly higher for males, with the mean for males at 3.36 and the mean for females at 3.20. The percentage of first-generation college students is 0.39 for males and 0.41 for females. Females, at an average age of 26.08, are slightly younger than males, with an average age of 27.32.

Table 14.2 displays coefficients from linear regression models predicting satisfaction-with-student-success-technology, stratified by gender. Model A1, which provides the baseline for males, shows that males who are first-generation college students are on average 0.08 higher on the satisfaction-with-student-success-technology scale than non-first-generation male students; this result is not statistically significant. Model B1, which provides the baseline for females, shows that females who are first-generation college students are on average 0.16 higher on the satisfaction-with-student-success-technology scale than non-first-generation female students; this result is marginally significant (p-value <0.10). Comparing Model A1 (baseline for males) and Model B1 (baseline for females), on average, the results suggest a student's first-generation status has a slightly stronger effect on females' satisfaction with student-success-technology (0.16, Model B1) than it does on males' satisfaction (0.08, Model A1)—gender could moderate the effect of first-generation status on satisfaction-with-student-success-technology tools.

Table 14.1 Descriptive statistics by gender

	Males	Females	Range
Student satisfaction-with-student-success-technology	3.36 (0.89)	3.20 (0.86)	(1, 5)
First-generation college student	0.39	0.41	(0, 1)
Age	27.32 (8.46)	26.08 (8.65)	(18, 64)
Race:			
White	0.63	0.67	(0, 1)
Hispanic or Latino	0.13	0.10	(0, 1)
Other race	0.18	0.17	(0, 1)
Asian	0.07	0.06	(0, 1)
Students (n)	234	467	

Note: Values below means in parentheses are standard deviations

Table 14.2 Coefficients from linear regression models predicting student's satisfaction with—student-success-technology, with gender as a moderating factor

	Males		Females	
	Model Al—baseline	Model A2—controls	Model B1—baseline	Model B2—controls
	B	B	B	B
First-generation college student	0.08 (0.12)	−0.06 (0.13)	0.16^{+} (0.08)	0.21* (0.08)
Age		−0.01 (0.01)		−0.01* (0.00)
Race:				
White (ref)		–		–
Hispanic or Latino		0.43* (0.19)		−0.12 (0.14)
Other race		0.48** (0.16)		0.19^{+} (0.11)
Asian		0.70** (0.23)		0.28^{+} (0.16)
Constant	3.33***	3.33***	3.13***	3.36***
R-squared	0.00	0.09	0.01	0.04
Students (*n*)		234	467	

Note: Values in parentheses are standard errors
$^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Model A2 in Table 14.2, controlling for age and race, shows that for every 1-year increase in age, first-generation males, on average and when compared to their non-first-generation peers, are slightly lower (0.01) on the satisfaction-with-student-success-technology scale. This effect is not statistically significant. Model A2 also shows that when considering a male student's race, on average, students who are not White are higher on the satisfaction-with-student-success-technology scale when compared to White males: Hispanic or Latino males are 0.43 higher (statistically significant; *p*-value <0.05); males of other races are 0.48 higher (statistically significant; *p*-value <0.01); and Asian males are 0.70 higher (statistically significant; *p*-value <0.001). First-generation college students who are males, when controlling on age and race (Model A2) and on average, are lower by 0.06 on the satisfaction-with-student-success-technology scale than their non-first-generation peers; results are not statistically significant. Compared to the baseline for males (Model A1), the direction of the relationship in the model with controls for males (Model A2) changes, suggesting that the relationship in the baseline could be due to spuriousness.

Model B2 in Table 14.2 focuses on females and includes controls of age and race. It shows that for every 1-year increase in age, females' satisfaction-with-student-success-technology decreases by 0.01 on average and controlling on other factors. This effect is marginally significant (*p*-value <0.10). Model B2 also shows that, relative to White females: the average satisfaction-with-student-success-technology of Hispanic or Latino females is 0.12 lower (not statistically significant); of females of other races is 0.19 higher (marginally significant; $p < 0.10$); and of Asian females is 0.28 higher (marginally significant; $p < 0.10$). First-generation college students who are females, when controlling on age and race (Model A2) and on average, are higher by 0.21 on the satisfaction-with-student-success-technology scale than their non-first-generation peers; results are statistically significant (p-value <0.05).

In Table 14.2, when comparing the results between first-generation males and females when controlling on age and race (Model A2 and Model B2), on average, and compared to their non-first-generation peers, the coefficients from linear regression models describe that first-generation females are higher on the satisfaction-with-student-success-technology scale (0.21; results are statistically significant; p-value <0.05) as compared to first-generation males (-0.06; results are not statistically significant). For both first-generation males and females, on average, their satisfaction-with-student-success-technology supports changed in reference to the baseline. This indicates that in the baseline model satisfaction-with-student-success-technology as predicted by first-generation status might be biased by spuriousness, i.e., factors that are related to both first-generation status and satisfaction. However, the relationship moved in different directions for each gender from the baseline model with the use of controls. A final interpretation of Table 14.2 is that net of controls, it also could be true on average that a student's first-generation status has a slightly stronger effect on females' satisfaction-with-student-success-technology (0.21, statistically significant, Model B1) than it does on males' satisfaction (-0.06, not statistically significant, Model A1), leading to the possibility that gender could moderate the effect of first-generation status on student-success-technology tools.

14.6 Conclusion

This study attempted to provide information to assist with improving e-service delivery related to universities' goals to improve undergraduate student's persistence and degree attainment for first-generation undergraduate college students. Student's success efforts are critical as the United States seeks to improve college attainment by focusing on first-generation college students, whose rates of persistence and degree attainment are substantially lower than their first-generation peers. The study used data from a survey of 701 Portland State University (PSU) students about the importance and satisfaction that students placed on accomplishing key tasks online (analytic sample).

The study sought to provide help with evaluating two hypotheses: (H1) Because first-generation students have less familiarity with college and experience more barriers in accessing it, they might be more satisfied with student-success-technology than their non-first-generation peers, as in many ways this technology is designed to help reduce barriers to succeeding in college; 2. (H2) For first-generation college students there will be differences in satisfaction with student-success-technology by gender.

When considering H1, first-generation college student's status and satisfaction with student-success-technology appear to be positively associated. For females, the overall results were statistically significant—female first-generation college students are on average more satisfied with student-success-technology compared to their non-first-generation peers. For males, the results showed that for male first-generation college students, on average, they are only slightly less satisfied with student-success-technology than their non-first-generation peers, with the results not being statistically significant. Finally, in relation to H2, as just described, the effect of first-generation status on satisfaction of student-success-technology differed for males and females: it is possible that gender could moderate the effect of first-generation status on student-success-technology tools. An interesting area of future research could be to more closely examine the results from this study that show that first-generation male students of color, on average, are more satisfied than their White first-generation peers.

The implications of the findings from this study are that there is some evidence that there are differences in first-generation students' experiences with student-success-technology and that for women, at least, student-success-technologies can aid them in navigating through college, perhaps by reducing digital barriers that might not be present for their non-first-generation peers. This supports the findings in related research that suggests there could be differences in how first-generation students access technology. More directly, this study is in line with the only directly related research we could find [4] that student success tools can help students who experience structural or circumstantial barriers to accessing higher education.

This study contributes to the literature by providing findings specifically about first-generation students and student-success-technology, in an effort to aid universities and educational technology companies with enhancing efforts to best to serve these students. For example, universities might want to continue to support student success e-services to enhance how they support first-generation students and more generally, start or continue efforts to design institutions that work best for the students they are trying to help. Additionally, related to [2, 7, 24, 37] this study provides indicators that universities ought to continue focusing on improving institutional environments, such as e-services, to aid with persistence and provide first-generation students with more of an advantage to account for familial and other backgrounds that do not prepare them for college.

Some limitations of this study merit mention. The analytic sample size was perhaps too small as it relates to male respondents, perhaps contributing to biased results and limiting generalizability. Further, there are likely unmeasured factors that we were not able to include, such as for example socio-economic background, amount of financial aid, and academic performance, which could have influenced the results.

In closing, higher education institutions have profound responsibilities, pressures, and goals to improve student success, and in particular, critical choices to make about how they promote or inhibit student persistence. The main findings from this study—that some subgroups of first-generation students on average benefit more from student-success-technology, when compared to their non-first-generation peers—suggest that technology can be an enabler and support the removal of barriers. Future research could use larger samples, control for more spurious influences, and be conducted with students at other universities to test the validity of this and other studies. Improving and innovating delivery of e-services/student-success-technology provides a ripe opportunity for institutions to minimize barriers to access, not to mention address students' frustrations with antiquated digital experiences, so that students can focus on what is most important—their learning.

Appendix: Survey Questions About Students' Satisfaction with Student-Success-Technology

I can see a visual representation of where I am in my degree
I can easily apply for scholarships
I can see all important deadlines and next steps in one place (especially related to enrollment, billing, and financial aid)
I can easily find internships related to my major
I can see incoming messages and notifications from all my PSU inboxes in one place (i.e., PSU Gmail, Google calendar invitations, D2L email/announcements, Banweb financial aid messages, etc.)
I can easily identify and purchase books and course materials
I can quickly fine my classes using an online map
I can see how much I will owe for the full academic year
I can easily find course descriptions
I can search all PSU online resources with quality results
I can view opportunities to engage with campus based on my major and interests (e.g., events, activities, student groups, etc.) in one place online
I can conduct all important PSU business through one site and one login
I can easily access and use PSU online resources and services from a mobile device
I am presented with a personalized experience when using PSU online resources
I can easily view my class schedule online
I can easily get to PSU online services from one place, such as PSU Gmail, Calendar, Banweb, D2L, etc.
I am notified of important deadlines and next steps related to my business at PSU

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Chapter 15
Assessing the Key Factors Impacting the Adoption and Use of Tethered Electronic Personal Health Records for Health Management

Saeed Alzahrani and Tuğrul Daim

15.1 Introduction

Information technology (IT) becomes crucial part of the healthcare system and it is getting more attention worldwide. Health IT includes well-known systems that have transformed the health sector, such as electronic health records (EHRs), electronic medical records (EMRs), and electronic personal health records (ePHRs). ePHR aims at enabling patients to take more active role in their care by providing them with a tool to access their health records in a secure and safe environment. The ePHR allows greater patient-provider engagement. The provider's adoption rate of the ePHR as a tool to connect with patients and to enable them to have access to their records is increasing at an accelerated rate. However, the patient's ePHR adoption rate remains low. In the United States, the number of office-based physicians adopting EHR increased from 17% in 2008 to 58% as of 2015. Similarly, the non-federal acute care hospitals with certified EHR rate increased from 9% in 2008 to 84% as of 2015 [1]. Despite the efforts to encourage the health care provider's adoption of certified EHR and ePHR, the adoption rate by patients remains below expectations [2]. The goal of this report is to investigate the key factors influencing the adoption and use of the ePHR in order to understand the patients' intentions of the adoption and use of such a technology. More attention is needed to improve the patient's adoption of ePHR. The factors influencing the adoption and use of the ePHR for health management are grouped into six themes. These themes include performance factors, effort factors, social factors, facilitating conditions, perceived credibility, health factors, and computer factors. The themes involve essential factors that influence the adoption and use, such as perceived

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usefulness, perceived ease of use, portal features, subjective norms, computer and internet availability, computer literacy, computer anxiety, privacy and security, health literacy, satisfaction with medical care, and provider's support.

15.2 Factor Influencing the Patient's Adoption of ePHR

There several key factors play an essential role in the ePHR adoption. This section will address the most key factors influencing patient's adoption of ePHR such as health literacy, usability, computer literacy, health information exchange (HIE) and interoperability, health care provider's support, ePHR features, patient characteristics, and health conditions. At the end of the report, a taxonomy of the factors is developed, and the essential factors are grouped in themes.

15.2.1 Health Literacy

The explosion of the internet and the massive amount of information available on the web have become a source for individuals to look up passively for health information. The available information on the web requires consumers to have the skills to search and evaluate the quality of the existing information related to their health in order to facilitate their health-related decisions.

Patient's health literacy is another factor that may prevent patients from taking full advantage of the ePHR. Patients may not have the interest to adopt and use a system that they find difficult to understand the information it consists of. Health literacy is defined as "the degree to which individuals have the capacity to obtain, process, and understand basic health information and services needed to make appropriate health decisions" [3]. The low health literacy can add a financial burden on the healthcare systems. Vernon et al. [4] studied the health literacy implications on the national policy. They stated that low health literacy costs the U.S. health care system and economy between $106 billion and $238 billion annually. Studies show that about one-half of American adults are shown to have low health literacy which would negatively impact their interest in the health information technology (HIT) adoption [5]. Health literacy also can be defined in terms of information technology as "the ability to read, use computers, search for information, understand health information, and put it into context" [6]. These two definitions emphasize the combination of the health information understanding and the information technology associated commands.

Mackert et al. [5] conducted a study to investigate the relationship between the health literacy and the adoption and use of HIT tools like fitness and nutrition apps, activity trackers, and patient portals. The study investigated the ease of use and usefulness of these tools as well as the perceived privacy and trust. The results show a positive relationship between the health literacy and the adoption and use of

HIT tools. Also, greater health literacy revealed greater perceived ease of use and usefulness of the HIT tools. In terms of privacy, a negative association is found between the health literacy and privacy perception toward HIT tools. The health literacy has a positive association with trust in healthcare but a negative association with trust in government [5].

Briones conducted a study [7] to examine how young adults evaluate the health information available on the web and how they ensure its credibility. Fifty face-to-face in-depth interviews were conducted to gather the views of the young adults, then, analyzed using techniques from the grounded theory approach. The findings suggest that young adults find online sources of health information to be an acceptable channel. Young adults perceive the social media sites as networking channels rather than a credible source of health information.

To measure the electronic health literacy, Norman and Skinner have developed a reliable tool called eHealth Literacy Scale (eHEALS) to assess the patients' knowledge, comfort, and perceived skills in utilizing the information technology for the health issues [6]. The eHEALS tool has been widely adopted and used to measure the eHealth literacy.

A study utilized "eHEALS" tool found out that patient's health literacy is a key factor in the patient willingness and interest to adopt ePHR [8]. It showed that 65% of the patients performed well in the health literacy scale which resulted in higher interest in the ePHR adoption [8]. Health literacy is influenced by various factors such as education level, income, and age [8]. It is found that people with less education and have a low income are shown to be less likely to look up health-related information online [9]. Heuristic evaluation and usability testing are two assessment tools that can be used with an added focus to detect health literacy issues from the patient portal [10]. Low health literacy influences the patient perceptions toward the value of the ePHR as well [11]. Oppositely, Cortelyou-Ward et al. [12] examined the patient engagement and patient-provider communication resulting from the use of ePHR to increase the patient health literacy which in return will improve the patient satisfaction and outcomes. They suggest the importance of considering the ePHR as a tool that improves the patient health literacy and education. The health literacy positively influences the adoption of ePHR. Health literacy plays a key role in the adoption of the ePHR. The level of health literacy demands on the patients and healthcare providers are deemed to be equally important in the ePHR adoption [13].

Validated translated into different languages versions of the eHEALS scale have been developed. These versions such as Dutch [14], Japanese [15], and Persian [16] versions developed to measure the health literacy of different nations and the tool has proved its reliability in measuring the eHealth literacy. A study [14] conducted in examine the validity of a Dutch translation of the eHEALS scales in two populations. The eHEALS was assessed and the results showed the high reliability as the internal consistency of the scale was high. Mitsutake et al. conducted a study [15] to test the validity and reliability of a Japanese version of the eHEALS (J-eHEALS) scales. The study as well aims at examining the relationship between the eHealth literacy and the demographic attributes. Internet-based cross-sectional survey was used to capture the responses of 3000 Japanese adults. The findings confirm the J-eHEALS as a highly validated and reliable scale. Dashti et al. conducted a study [17] to evaluate the level of e-Health literacy of Medicine and Health Sciences University students in Iran. The study utilized the e-Health literacy scale (eHEALS) but with a validated Persian translated version (P-EHEALS). The findings show that there is a low level of e-Health literacy among Medical and Health Sciences University students in Mashhad, Iran.

A study [18] used the eHealth Literacy Scale (eHEALS) to provide a better understanding of the eHealth literacy among college students and their health behaviors. It aims as well to understand their use of online resources to maintain their health. The results of surveying 422 college students revealed that eHealth Literacy Scale (eHEALS) showed a significant association for students' current and future maintenance of health and use of online health resources.

Petrič et al. provided an extension of the eHealth Literacy Scale (eHEALS) to better understand the different types of online health communities (OHC) users [19]. The study was based on a cross-sectional web survey on a representative sample size of 644 users of the OHC. The extended eHEALS scale presented six dimensions: awareness of sources, recognizing quality and meaning, understanding information, perceived efficiency, validating information, and being smart on the net with the awareness of the various online sources being the most developed and the understanding information being the least developed dimension. The study identified four types of OHC users: active help-seekers, lurkers, core relational users, and low-engaged users. The findings showed statistically significant differences among the four user types across the six dimensions. The active help-seekers users are shown to have strong eHealth literacy skills and the ability to filter through online information [19].

Another method developed to explore health literacy is the Rapid Estimate of Adult Literacy in Medicine. A study was conducted in Mashhad, Iran [16] to examine women's health literacy using cross-sectional approach. The study used a translated to Persian version of the Rapid Estimate of Adult Literacy in Medicine. The results of the study show that younger women have low health literacy than older women. The education level appeared to be a key determinant of the level of women's health literacy. The study shows a positive correlation between health literacy and both age and education.

15.2.2 Usability

The ePHR portal usability is an essential factor in the adoption. The usability of the ePHR portal includes the ability of the patient to navigate through the website smoothly, learn and use the portal easily, find information easily and quickly, spend short time completing the task, make minimal errors, and prefer the portal to search for health-related information over other websites [20]. There are some barriers of use that have been noted such as the ability to use and access to computers and internet for some people especially [21] older adults.

Ease of use has been an essential construct of many models that examine technology acceptance and use such as technology acceptance model (TAM) and unified theory of acceptance and use of technology (UTAUT). A study used protection motivation theory (PMT) & UTAUT models to examine the patients' intentions to adopt ePHR showed the factor perceived ease-of-use as significant factors in influencing the use of PHR [22]. A study of the physicians "acceptance of PHR using UTAUT model suggested that Performance Expectancy is the most significant factor affecting physicians' acceptance of PHR [23]. The Diffusion of Innovation Model was applied to test the patients" perceptions of the ePHR found that ease of use, relative advantage, and trialability best predictors of the ePHR value [24]. Another study examined the patient's adoption of the ePHR using UTAUT revealed that performance expectancy and effort expectancy are the drivers of the ePHR adoption [25].

Usability evaluation on the health IT context can be a complex and costly process and depends on various factors such as number end-users or patients in the case ePHR, the patient portal, and the process of the evaluation itself [26]. Usability of the patient portal or ePHR can be measured through heuristic evaluation or usability testing [10]. Heuristic evaluation is one assessment tool for ePHR that is conducted at low-cost and has proved its success in identifying the challenges to use of such a system [26]. Heuristic evaluation depends on the specialists who evaluate and examine the portal to detect and note any usability issues that may influence the usability of it [10]. On the other hand, usability testing depends on the patients interacting with portal while the specialists observe the patients interaction, and analyze and record any issues that the patients face [10]. Human-centered design method evolves around the patients and allows them to shape the design of the end version of the portal and improve its usability [20]. In this method, participant patients are asked to perform certain scenarios in the patient portal and think aloud as they proceed. They also complete surveys and conduct interviews thereafter. The results then analyzed to present design improvements [20].

A study conducted to evaluate usability and usefulness of ePHR for older adults analyzed four components of the ePHR which are tasks, users, representations, and functions [27]. It found out that the tasks were easy for the patients to learn and apply even though the performance time appeared to be slow [27]. University of Victoria's eHealth Observatory has evaluated the Personal Health Portal (PHP) of Alberta Health facility in Canada focusing on the pre-design, design, and adoption assessment using persona-based usability inspection combined with usability testing sessions. The study focused on the early usability assessment of the PHR application and found out that there is a great opportunity for improvement that can add tremendous value to users in different areas of the PHR information architecture, content, and presentation [28]. Overall, it is important to consider the patients in the process of designing the ePHR. Failure to do so may lead to human errors and difficulty to use which would lead to unsatisfied patients that may result in abandoning the system and slow rate of adoption.

15.2.3 Health Information Exchange (HIE) and Interoperability

Both health information exchange (HIE) and interoperability involve the transfer of information either from one health care provider or system to another. They pose a crucial role in the adoption and acceptance of the ePHR since they help in providing a full picture of the patient health record. It is important to mention and understand the difference between the HIE and interoperability as they involve the transfer of patient health information.

15.2.3.1 Health Information Exchange (HIE)

The HIE is perceived to have two definitions: one as a verb and a second as a noun. Healthcare Information and Management Systems Society (HIMSS) defines the verb HIE as “the sharing action between two or more non-affiliated organizations with an executed business/legal arrangement that have deployed commonly agreed-upon technology with applied standards for the purpose of electronically exchanging health-related data between the organizations” and the noun form of the HIE as “a catch-all phrase for the health information exchange organizations (HIOs) providing data exchange under the legal arrangements” [29]. It is important to mention the regional health information organization (RHIO) as an important element in the health information exchange process which is defined as “a type of health information exchange organization (HIO) that brings together health care stakeholders within a defined geographic area and governs health information exchange among them for the purpose of improving health and care in that community” [30]. Based on the HealthIT.gov, HIE “allows doctors, nurses, pharmacists, other health care providers and patients to appropriately access and securely share a patient’s vital medical information electronically—improving the speed, quality, safety and cost of patient care” [31]. The HIE aims at achieving the goals of improving healthcare quality, enhanced workflow efficiency, and reduced cost [32]. Efficiency improvement includes being able to access test/lab results from other providers and improve the efficiency of the office administration workload regarding handling referrals and claims processing [32]. The concerns related to HIE may include technical and organizational ability of the health provider, privacy and security, and cost concern [32]. There are three forms of HIE: direct exchange, query-based exchange, and consumer-mediated exchange [31]. The Office of National Coordinator (ONC) works toward supporting governance initiatives of nationwide HIE to: enhance interoperability, reduce the cost of information exchange, and increase trust among participant involved in the HIE process [33]. There have been many studies that have examined the ePHR and HIE. Patients and health providers express an interest in using ePHR for the purpose of accessing, sharing, and exchanging vital health information such as medical history and medication list which would not be possible without the HIE existence [34]. Another study examined the patient’s perceptions and attitudes toward PHR and HIE use by their health provides [35]. The study showed a great patient's interest in ePHR and to access their health information and concluded by emphasizing the importance of addressing the issues related to privacy and security as part of HIE process. Patel et al. [36] examined the patient's support for HIE and PHR and concluded that patients support the physicians' use of HIE. It emphasized the importance of demonstrating the benefits of HIE to the underserved population in order to achieve a higher rate of HIE acceptance and support [36]. The HIE is an essential element of the ePHR success as it allows the exchange of patient health information across different health care providers for the purpose of supporting and providing better healthcare service.

15.2.3.2 Interoperability

The interoperability between the systems that deal with ePHR is an essential success factor for ePHR adoption. Healthcare Information and Management Systems Society (HIMSS) defines interoperability as "the extent to which systems and devices can exchange data, and interpret that shared data" [37]. Department of Health and Human Services (HHS) and ONC annual progress reports submitted to the U.S. Congress stated the importance of building interoperable health systems [38]. The tethered ePHR is built upon the successful interoperability between the EHR and the ePHR portal.

Archer et al. [39] conducted a literature review on the ePHR. They suggest that having a functional ePHR relies on the existence of unified technical standards for the system interoperability [39, 40]. Interoperability is considered as a key factor in the successful ePHR adoption [40]. The standards of building interoperable ePHR include security and privacy standards, adoption and use of certified HIT solutions, and data interchange standards [39].

In order to build interoperable health system, HHS highlights the key priorities to provide seamless and secure flow of health information that includes propose standards to enable the seamless and secure exchange of health information, build business case for interoperability, and change the culture around access to health information. The activities involved in building the business case for interoperability in order to better assist the smooth information flow include moving toward value-based care, supporting health care providers utilizing Health IT by providing technical assistance and sufficient guidance and resources, and CMS funding to foster the electronic health information flow [38]. The ONC aims at changing the culture around access to health information by supporting the rights of patients to access their health information, efforts to discourage information blocking, and encouraging transparency as indicated in the annual report. It also emphasizes the interoperability commitments to ensure proper consumer access, transparency, and electronic health information standards implementation [38].

HIMSS has formed a group of HIE and interoperability experts to prepare a comprehensive business case for the adoption of HIE and interoperability. The group has identified some challenges and barriers to HIE, and interoperability adoption [29]. The cost associated with having such systems may include hardware, software, implementation and ongoing training, maintenance, and staffing [29]. Also, barriers identified in the report include lab data transmission standards, privacy and security, long-term care/behavioral health, semantic and syntactic interoperability, and competing and conflicting document standards. The existence and success of HIE and interoperability in the health care system allow for the successful exchange of essential health information and in return improve the chance of other systems such as EHR and ePHR success. The document as well presents the benefits of successful implementation of HIE attained by hospitals, physicians, patients and health information organizations such as improved and efficient workflow, faster and easier access to various health information, better decision making by having necessary data in hand, more patient's involvement in their care, and reduction in healthcare costs. The utilization of HIE and better interoperable systems resulted in, as per pilot study presented in the report 53% drop in non-urgent visits to ER, 68% an increase in primary care visits, and cost saving of between two and four million dollars over a period of 6 months.

15.2.4 Computer-Related Factors

Patient's ability and knowledge to utilize computer have considerable influence on the adoption of health technologies. These factors include computer literacy, access to computer and internet, internet reliance required by certain technologies such as ePHR, computer self-efficacy, computer anxiety, and personal IT innovativeness. Computer literacy requires the ability to have access to the computer and use it to solve a problem or accomplish certain task [41]. Computer literacy contributes to the ability of the patients to effectively adopt and use the ePHR [42]. The technology related factors are essential in the adoption process of the ePHR.

The relationship between the patient's computer knowledge and the adoption of the HIT has been investigated by many researchers. Saranto and Leino-Kilpi examined computer literacy in nursing [43]. They used a three-round Delphi survey to extract knowledge from experts. The results showed that nurses are required to have computer knowledge and skills especially in accessing and using the hospital information system as well as be aware of the computer security threats and implications [43].

Computer availability and literacy are among the top barriers facing the adoption of ePHR. Computer-related barriers that limit the utilization of the ePHR include the patient's lack of computers and nurses' negative attitudes regarding computer usage [44]. In a study examining the barriers to the use of ePHR by an elderly population, computer literacy, and computer anxiety were ranked as the top major barriers in using ePHR by elderly population [45].

Cocosila and Archer empirically investigated the patients' perceptions on the adoption of ePHR [46]. The study examined factors to predict the intention to adopt ePHR that include: internet reliance, computer self-efficacy, personal IT innovativeness, security and privacy and trust, anxiety, and perceived usefulness. The findings showed that personal IT innovativeness and perceived usefulness are the top factors influencing ePHR adoption. The findings as well showed a positive impact on the adoption by the following factors: internet reliance, security and privacy, and trust constructs. The access to the internet and computer literacy are presenting the digital divide concept.

The term “Digital Divide” has emerged to describe the access to computer by people. The digital divide is defined as “the gap that exists among individuals and communities with regards to the ‘haves’ and ‘have-nots’ of information and modern communications technologies” [47]. Digital divide represents the “disparities among subgroups based on access to the Internet and computer literacy” [48]. Digital divide is shown to be a problem facing the ePHR adoption and use [49]. The Pew Research Center’s estimates an increase in the number of people accessing the internet. Eighty-nine percent of U.S. adults in 2018 are estimated to have accessed the internet in comparison with 74% a decade ago [50].

Different technology adoption models have considered the computer-related factors to measure and predict the ePHR adoption. The task-technology fit (TTF) model studies how technology support people accomplish tasks by examining the technology characteristics, task characteristic, task-technology fit, performance impact, and utilization [51]. One of the unified theory of acceptance and use of technology model four constructs, facilitating conditions examined the degree to which an individual believes that resources and technical infrastructure exists to support the use of the ePHR [52].

In the context of health IT, computer literacy has generated and new concept call eHealth literacy. Ehealth literacy is a concept that has been developed to combine the computer literacy and health literacy. It is defined with regards to the patients as “ability to seek, find, understand, and appraise health information from electronic sources and apply the knowledge gained to addressing or solving a health problem” [41]. It is also shown that there is a positive relationship between health literacy and use of internet-based technologies [9].

15.2.5 Health Care Provider’s Support

The support and encouragement of the health care providers, physicians, nurses, and hospital administrators to the patient’s adoption of the ePHR are crucial. A study about the patient portal and patient engagement showed the importance of the provider’s acceptance and promotion of the ePHR [48]. Studies show that there is an increasing attention from the clinical staff in educating and supporting patient to use and access the patient portals [53].

Nazi conducted a study using in-depth interviews with 30 VA health care professionals who are engaged in providing direct patient care to examine the health care professionals’ perspectives toward the ePHR in organizational and clinical settings [54]. The author believes that the current efforts focus on the patients’ adoption of ePHR as a tool for them to take more control over their health, and was designed as patient-oriented tools without taking into consideration the role of the social and organizational context of health care delivery. It is believed that the nature of the patient engagement is a reciprocal process. The study presented various factors such as adequate education and training opportunities that facilitate the health care professionals' endorsement of the patient adoption and use of the ePHR as this endorsement has been limited. The provider's endorsement is a continuous process that starts from influencing the patient's decision to adopt ePHR to the engagement and continuous adoption to reach positive outcome. The study shows that health care professionals are shown to have a limited view of the patient adoption, and use of various ePHR functions such as access to the health education materials and track their health history reports. The health care professionals have the perceptions and concerns that the patients fear that their entered data in the ePHR could be viewed by the health care team. One of the main reasons of the insufficient endorsement by health care professionals is the lack of integration between the ePHR (My HealtheVet) and the Veterans Affair's electronic health record (VA-EHR). The study highlights the importance of the health care professionals' endorsement of ePHRs to patients and in the engagement along the way. Also, the study emphasizes the importance of the patients' and physicians' utilization of the ePHR tools together as partners.

Nurses play a key role in the ePHR introduction to the patients and as a promotion role model. A study examined the intentions of nurses to adopt patient's ePHR [55] suggests that subjective norms had the most significant influence on the attitudes and intentions of nurses to use e PHRs as they are influenced by their peers. It emphasizes the importance of nurse's contribution to the development and promotion of the ePHR as well. Nurses can add insight into the development and revisions of the ePHR [11].

On the other hand, patients trust their physicians and are willing to follow their advice to adopt and use ePHR if they recommend it to them [46]. Vydra et al. [56] emphasized the importance of the physician endorsement for the ePHR to gain widespread diffusion. They highlighted the significance of rewarding the employee using ePHR the most, providing financial reimbursement for workload resulted from the time spent on the ePHR communicating with the patients, and providing more ePHR educational materials. Satisfaction with healthcare provider and the current medical care improve the chances of the patient adopting and using their provider's ePHR [46].

The ownership of the ePHR software appears to matter to the patients. A study conducted to investigate the patient's and physician's willingness and interest to adopt and use ePHR in the emergency department [57]. The study showed that patients prefer the hospitals as the source of the ePHR and to control their health information rather than any other entities such as the software companies, the government, and insurance company.

The healthcare entities should put more efforts in promoting the adoption and use of ePHR among patients. Wells et al. conducted a study to examine the organizational strategies of the health care providers who had implemented PHRs for at least 12 months to promote PHR adoption using semi-structured interviews and a web-based survey [58]. The study identified the health professional encouragement and endorsement as the most effective strategy to promote the ePHR and improve the patient acceptance. Also, raising patient awareness of the ePHR existence and benefits, and the provider acceptance are among the main organizational strategies to promote ePHR. The study summarizes the main providers' strategies as the organizational vision actively communicated, clear governance and policies, enforce work process redesign, staff training, information technology (IT) support, and monitoring and incentives. Another study suggests that in order to promote the adoption of ePHR, policymakers should provide sufficient assistant in the forms of financial support, interoperability, and training of information technology support staff [59]. It is obvious that the role of health care providers, physicians, and nurses on promoting the ePHR adoption and use is an important success factor toward the widespread of the ePHR adoption.

One of the main goals of the "Meaningful Use" initiative released by the Office of National Coordinator (ONC) is to engage the patients and health care providers. For the health care providers to be eligible for the meaningful use incentives, they should meet certain criteria that influence the patient's adoption and use of the ePHR. As part of the meaningful use Stage 1, the healthcare provider must provide the patients with the ability to view, download, and transmit their health information [60]. Also, the meaningful use Stage 2 requires that 5% of the healthcare providers patients' population use secure e-messaging in order to qualify for the meaningful use Stage 2 incentives which require direct interaction between the patient and the health care provider [61]. Giving the patients the ability to access their information is measured as the following: more than 50% of the patients are to be given online access to their records which are mostly provided during the doctor visit for the first time [60].

Health care providers, physicians, and nurses may have positive and negative perceptions toward ePHR which may influence their endorsement of the ePHR adoption to the patients. Physicians are attracted to the features that empower patients to engage effectively in their care but are concerned regarding the data management, practice management problems, and changes to the patient–physician relationship [62]. Physicians are interested in having their patients enter their health data and update their medication list in the portal, so they can go over them with their physicians in the visits while the nurses interested in giving the patients the ability to access information that they may need later [54]. Pharmacists expect an increase in the workload and the prescription refills that have to fulfill due to the increase in the secure messages related to prescription refills [54]. Some physicians perceive that may patients may have low levels of computer and health literacy, and low levels of interest and motivation to use the ePHR which may hinder their effort to encourage their patients to adopt and use the ePHR [63]. Clinic personnel believe that patient portals can improve the patient-provider communication, increase efficiency, and enhance information sharing, while, their concerns are evolved around the potentiality for the workload to increase, health disparities increase, privacy issues, and to confuse the patients [64]. Clinic personnel expected an improvement in the patients' satisfaction and trust with their healthcare providers [64]. The more experienced in the practice the physicians, the more they are willing to dedicate the time to interact with their patients through the ePHR, despite, the belief that the lack of reimbursement for the workload and time spent interacting with the patients through the ePHR as a major barrier in using and supporting the adoption of the ePHR [56].

It is important to understand the perceptions of the physicians before and after the adoption and implementation of the ePHR in their facilities. Physicians who perceived an increase in the workload due to the ePHR implementation, had an opposite respond after the implementation and expressing no change on the level of the workload [65]. Staff should receive appropriate training and education about the benefits of the ePHR to the practice as well as the patients themselves. Realization of the benefits of the ePHR should foster its adoption and encourage health care staff in promoting it to their patients. The perceptions of the health care providers, physicians, and nurses should be addressed in order to gain their support and endorsement toward the patients' adoption of the ePHR.

15.2.6 Health Condition

The health condition and ePHR adoption appear to have a positive correlation. Many researchers have examined the adoption and use of ePHR for chronic condition management. Patients with chronic diseases tend to be more adopters to the ePHR than patients with less complex health condition [53, 66]. According to the connecting for health report which is part of the Markle Foundation's [67], patients with chronic diseases tend to have a higher interest in the ePHR with a percentage of 65% compared to 58% of the patients without chronic diseases. Studies suggest the utilization of ePHR as a method to improve chronic disease self-management [2]. Irizarry et al. [48] showed that patients with chronic conditions and disabilities have a higher rate of adoption and use of the ePHR. The health condition may play a factor in the ePHR adoption.

Laugesen and Hassanein have developed a theoretical model for ePHR adoption by chronic disease patients as self-management tool [2]. The model intends to explain the health-related behaviors through the protection motivation theory (PMT) and information technology adoption through task-technology fit (TTF) theory in combination with the health self-management readiness concept of the patient activation measure (PAM). The new theoretical model was tested and validated vis statistical model by surveying diabetes patient. The results of the model indicated that all constructs used in the models showed significant influences on the patient's intention to adopt an ePHR for the chronic condition management.

A systematic review conducted in 2015 on 27 selected articles investigating the patient and provider attitudes toward the use of patient portals for the management of chronic diseases [68]. The study revealed substantial improvements in the patient with chronic disease self-management and the quality of care provided by the providers has enhanced. Also, there were positive and negative attitudes toward the patient portal. Patient-provider improved communication represents the positive attitude and the security concerns and user-friendliness were the negative attitudes noted [68].

The ePHR has been used as a health management tool for various health conditions, such as diabetes, asthma, cancer, and for the children's health care. The ePHR is used to help diabetes patients in better managing their health. A qualitative study is conducted to study the use of ePHR to improve diabetes management [69]. The study was intended to capture the perspective of the patients, general practitioners, nurses, diabetes educators, and clinical staff about the ePHR as an online diabetes management tool. The study identified four themes: disease management facilitators, challenges to ePHR use, the communication between the patients and providers, and ePHR system improvement recommendations. The results of the study showed that patients are more engaged in their care due to the ePHR as a management tool and emphasize the role of the healthcare providers as facilitators of disease management. The ePHR also has been used in the primary care settings to manage chronically ill children. The ePHR adoption is investigated in the primary care setting, as well, as a management tool of pediatric asthma [70]. The study aims at exploring the results of potential improvement in the patient–provider communication due to the ePHR adoption and use of the clinical outcomes. The findings suggest that patients with uncontrolled asthma appeared to have more medication changes and clinic visits after starting to use the ePHR compared to the year earlier. It noted that the adoption rate is unlikely to be achieved in the short-term and the more efforts are required in the ePHR implementation phase [70]. Pai et al. conducted a study to capture feedback from prostate cancer patients who were given access to an ePHR in order for them to view their medical records and use a set of support tools [71]. Information about usability, satisfaction, and concerns with the ePHR were gathered. The findings showed that the most used functions were test results and transcribed doctor's notes. Prostate cancer patients in the study showed positive responses regarding the use of ePHR with high satisfaction rate, being able to find answers to their questions, and privacy was preserved. They as well agreed that the ePHR has improved their communication with their physicians and would continue to use it in the future.

Clark et al. have explored the current ePHR adoption by parents as caregivers to manage their children's health care [72]. The study aimed at capturing the parents' perspective and have found out that the main reason for the parents chose not to use ePHR to manage their children's health care is the low perceived need to do so. It showed as well that the most used functions of the ePHR for the parent's adopting ePHR are checking lab results and immunization records.

15.2.7 Portal's Features

The ePHR features and functionalities have positive influences in the ePHR adoption. Patients want to have more control over their records and be able to explore a wide range of the portal's features. In some cases, patients use the ePHR because they like certain features that they use frequently. The ePHR offers many features, such as patients access to their health information, summary of recent doctor visits, discharge reports, medications lists, immunizations records, secure messaging for patient-provider communication, prescription refills request, lab/tests results review, medical appointments scheduling, and educational materials access [73]. A study found that the features of the ePHR that patients use most frequently include: checking their lab results, being informed of health changes, and managing chronic disease [74].

Communication tools allow patients to take an active role in their health care and improve the relationship with their providers. Secure messaging feature facilitates the communication with the healthcare providers to better assist informed health decisions, and is considered one of the most used collaborative communication features by patients [53] alongside with medication reconciliation [48]. Secure messaging allows access to health care without, in many cases, the need for in-person visits as well as improving the quality of the doctor visits [66].

The Foundation for Accountability (FACCT), as part of the Markle Foundation's Connecting for Health program, studied the ePHR functionalities and their usability by surveying 1246 online individuals between 2002 and 2003 [67]. The features of the ePHR that were tested are messaging doctors, checking immunizations, note mistakes in one's record, transfer of information to new provider, and test results. The findings showed that over 70% of respondents have an interest in using one or more features of the ePHR, 35% would use 7 or more features if they were available, 75% use ePHR to communicate with doctors through email, 69% to track immunizations, 69% to track mistakes in their records, 65% to transfer information to new healthcare provider, and 63% to check the test results. The more features and functionalities offered to the patient through the ePHR, the more interested and engaged they are.

Meaningful use initiative requires providers to allow patients to have access to view, download, and transmit their health information [60], as well as, requires that 5% of the healthcare providers patients' population use secure e-messaging to improve the communication between the provider and the patient [61]. The availability of the more practical features of the ePHR encourages the patient's adoption and use of such an innovative health management tool.

15.2.8 Patients Characteristics

Patients have various characteristics that may influence their intention to adopt ePHR. Current research has demonstrated that patients' interest and ability to use ePHR is strongly influenced by personal factors such as age, ethnicity, education level, health literacy, health status, and role as a caregiver [48]. Health care delivery factors, mainly provider endorsement, and patient portal usability, also contribute to patients' ability to engage through and with the ePHR [48].

A study examining the digital divide in the adoption and use of ePHR investigated the characteristics of the ePHR adopters and non-adopters based on the activation of the ePHR online account given by their health providers and the frequent use [75]. The study showed that the percentage of patients adopting ePHR is 43% out of 75,056 patients representing the population of the patients in a certain health care facility. The study indicated that the adoption and use of ePHR among certain populations such as underserved, low-income, and elderly seem to be low due to factors like lack of access to computer or internet and fear of using such a computerized system. The study showed that White population have a higher rate of ePHR adoption in compared to Black and Hispanic population as the race could be used as a determinant factor of the adoption. Also, people with higher income appeared to have a higher adoption rate than people with lower income. This chapter concluded with the statement that the following factors increasing the number of chronic diseases, race/ethnicity, and insurance status are used to predict the intensity of the ePHR usage.

People with different race and ethnicity appear to have different perception toward the adoption and use of the ePHR. A study indicated that there is a low rate of adoption by the race and ethnicity. It is as well shown that it might be a result of either the lack of interest and motivation in such a system [53] or the availability of the computer and internet connection [76].

Elderly population as potential ePHR adopters are an important segment of the ePHR adoption and use. A study investigated the older adult's perspective on the adoption and use of ePHR interviewed 74 elderlies to capture their perspective [77]. The finding showed that only 20% reported using ePHR. The interviewee cited the most valuable features of the ePHR as the ease of access to health records and direct messaging and communication with health providers. The study highlighted the lack of computer proficiency, internet costs, and security concerns as the barriers to adoption by the elderly. It indicates the importance of taking into consideration the elderly perspective when designing and implementing ePHR.

Sakaguchi-Tang et al. conducted a systematic review to study the ePHR use and experience among older adults [21]. The review identified two barriers: privacy and security concerns, and lack of competency to use technology. The study highlighted two facilitators: technical assistance availability and family and provider advice.

Czaja et al. studied the use of ePHR by underserved adult population to perform health management activities [78]. The results showed that older adults consider ePHR as a valuable tool despite not being able to complete certain tasks and needed assistance. It can be concluded that the race/ethnicity, income, and age factors influencing the adoption and use of ePHR. Barriers that should be considered in designing the ePHR and influence the adoption include the lack of computer and internet access, the fear to deal with technology or perform certain ePHR tasks, and the need for assistance.

15.2.9 Perceived Credibility (Privacy and Security)

Privacy and security of health information can pose a huge threat to the ePHR adoption. The patients' health information is dispersed and distributed among various systems that are aggregated and then transferred to the ePHR for the patients to access. Through the data transmission process, security issues may occur. Furthermore, data governance and access rights determine who has the access right to what part of data which also may threaten the patient health information privacy. The importance of security and privacy of the patient health information are as equal as having interoperable system that allows the patient to access their information from various sources in a unified ePHR. Steele et al. identified three important security and privacy components of the patient health data in the ePHR [79]: who controls the access policy of the data, who is responsible for the physical security and policies, and the technical mechanism for achieving data security.

The security and privacy of the patient's health information is a critical component of the health process as if the patients lose their trust in the system or feel their confidentiality is being compromised, they may not want to share the full details of their health information with their health providers [80]. There are a variety of privacy and security threats. These threats may include insider abuse; accidental disclosures, insider curiosity, and insider subornation; secondary users; and outsider intrusion [81].

A study found out that about 91% of the patients are very concerned regarding their health information being secure and safe despite their belief that ePHR systems are safe and their health information are protected [67]. In the case of the chronically ill patients, patients value some of ePHR features over the privacy and security and feel less concerned about their health information privacy [67]. Dontje et al. ranked the security issue as one of the barriers of ePHR adoption factors [11]. Ong et al. added a new construct to the TAM called perceived credibility to test the consumer's acceptance of a certain technology [82]. Perceived credibility is defined with regards to the ePHR as the degree to which a person believes that using ePHR would be free of privacy and security threats [82]. A survey-based study was conducted to investigate the factors that motivate nurses to protect the privacy of electronic medical records (EMR) [83]. The findings suggest that the factors of attitude, subjective norm, and perceived behavioral control of the nurses significantly predicted the nurses' intention to protect the privacy of EMR. The privacy and security of the ePHR are essential factors influencing the patient's adoption of the ePHR.

The Health Insurance Portability and Accountability Act of 1996 (HIPAA) aims at developing regulations and policies to protect the privacy and security of the health information. The HIPAA standards aim at protecting health information and ensure secure transmission of the electronic transferred health information. These rules allow healthcare providers to adopt and implement new innovative technologies to improve the quality of provided care while ensuring the privacy and security of the patient's health information [84]. The health care providers under the HIPAA privacy rule are committed to provide patients with a notice of privacy practices (NPP) and respond to patients' requests that include: access to their protected health information (PHI), confidential communications, and restrictions on uses and disclosures of their health information [85]. HIPAA laws and regulations regarding the privacy and security of the patient health information have had a significant impact on the health care industry including the way, health care providers communicate with the patients and their families.

15.3 Taxonomy of Factors Related to the Adoption and Use of ePHR

This section identifies the key factors retrieved from previous research on the adoption and use of the ePHR and the technology adoption and use theories and models. These factors are important as they are related to the adoption and use of the ePHR for health management. A taxonomy of the key factors related to the adoption and use of ePHR technology has been developed, and a classification of the related factors into six main variables is constructed as shown in Fig. 15.1. The six main variables are shown to have been determinants of the patient's intention to adopt and use the ePHR for health management. The six main factors are performance factors, effort factors, social factors, facilitating conditions, perceived credibility, health factors, and computer factors. The factors included under performance are perceived usefulness [22, 23, 25, 46, 51, 55, 86–89], relative advantage [24], and portal features [67, 74, 77]. Effort factors include perceived ease of use [20, 22–25, 27, 28, 46, 51, 55, 86–89], and complexity. Social factors include subjective norms [22, 23, 25, 55, 83, 90] and self-perception [22, 25]. Facilitating

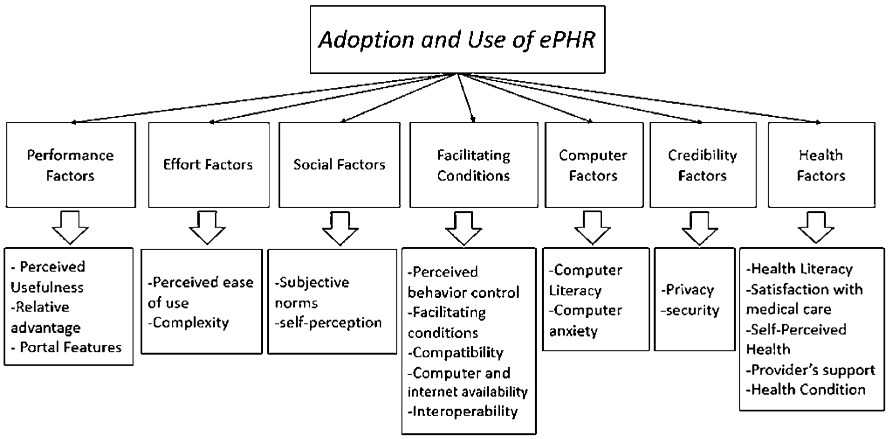

Fig. 15.1 Taxonomy of factors related to the adoption and use of the ePHR

conditions include perceived behavioral control [83, 90], facilitating conditions [23, 25], compatibility [24], computer and internet availability [21, 46, 91], and interoperability [31, 37, 39, 40, 59]. Perceived credibility includes two main factors privacy [11, 24, 46, 55, 67, 82, 83, 86, 91] and security [11, 24, 46, 55, 67, 82, 86]. Health factors covers consumer's and provider's health-related aspects, such as health literacy and eHealth literacy [6, 8, 11, 12, 41], satisfaction with medical care [46, 57, 92], self-perceived health [91], provider's support [11, 46, 48, 53, 56–59, 69, 88], and health condition [48, 53, 66, 67, 69, 71]. Computer factors involve factors other than the ones dealing with the computer as infrastructure computer literacy [41–43, 45, 46] and computer anxiety [41, 45]. These factors are perceived to influence the adoption and use of the ePHR for health management. Further evaluation, validation, and selection of only the most crucial factors are required in order to construct the final model.

Table 15.1 shows the taxonomy of the factors related to the adoption and use of the ePHR.

Table 15.1 Factors related to the adoption and use of the ePHR

Theme	Factors	References
Performance factors	Perceived usefulness	[22, 23, 25, 46, 51, 55, 86–89]
	Relative advantage	[24]
	Portal features	[67, 74, 77]
Effort factors	Perceived ease of use	[20, 22–25, 27, 28, 46, 51, 55, 86–89]
	Complexity	
Social factors	Subjective norms	[22, 23, 25, 55, 83, 90]
	Self-perception	[22, 25]
Facilitating conditions	Perceived behavioral control	[83, 90]
	Facilitating conditions	[23, 25]
	Compatibility	[24]
	Computer & internet availability	[21, 46, 91]
	Interoperability	[31, 37, 39, 40, 59]
Computer factors	Computer literacy	[41–43, 45, 46]
	Computer anxiety	[41]
Credibility factors	Privacy	[11, 24, 46, 55, 67, 82, 83, 86, 91]
	Security	[11, 24, 46, 55, 67, 82, 86]
Health factors	Health & eHealth literacy	[6, 8, 11, 12, 41]
	Satisfaction with medical care	[46, 57, 92]
	Self-perceived health	[91]
	Provider's support	[11, 46, 48, 53, 56–59, 69, 86, 88]
	Health condition	[48, 53, 66, 67, 69, 71]
Other potential factors	Patients' characteristics	[9, 53, 75, 91]
	Computer self-efficacy	[22, 24, 46, 55, 87, 93]
	Personal IT innovativeness	[46, 87]
	Patient activation measure	[93]
	Attitude	[55, 83, 87, 88, 90]
	Habit	[25]

15.4 Conclusion

Electronic personal health record (ePHR) helps support patient-centered healthcare by allowing patients to access their health information from their provider's EHR. This report is intended to investigate the key factors impacting the adoption and use of the tethered electronic personal health records (ePHR). This report retrieved the key factors from previous research on the adoption and use of the ePHR and the technology adoption and use theories and models then the taxonomy was created. The key factors are grouped into themes. These themes include performance factors, effort factors, social factors, facilitating conditions, perceived credibility, health factors, and computer factors. The themes involve essential factors that influence the adoption and use of the ePHR, such as perceived usefulness, perceived ease of use, portal features, subjective norms, computer and internet availability, computer literacy, computer anxiety, privacy and security, health literacy, satisfaction with medical care, and provider's support.

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Chapter 16
Design Study of Medical Device

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Intense competition has become the norm in most markets in recent years, due to globalization and technology advancements among other reasons [1–3]. Therefore, it is an essential necessity for firms that want to stay relevant and competitive, to seek innovation and creativity in new product development (NPD) process, while trying to maintaining high quality, low prices and short time-to-market periods to survive in such changing marketplace [4–6].

Medical devices industry is an industry where intense competition and modern market challenges are clearly evident [7]. Firms manufacturing medical devices face the same competitiveness challenges facing any industry in modern markets. In addition, there are challenges specific to this industry as the process of medical device design is difficult, complex and requires collaborative work and knowledge transfer between medical and engineering experts. In fact, the medical device design is a very specific area that includes complex procedures, various users, human factors and science [8–11].

This chapter aims to investigate and propose an approach for how to identify design requirements for medical devices that address the various competitiveness and innovativeness requirements of medical devices, through using multiple techniques with focus on the human and technology. In order to do that, this chapter research will focus on medical crutches as an example. Existing crutches in the

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market will be explored to identify temporary user needs and failures of product features. The aim is to explore the main problems of existing crutches in the medical market. Then, introduce a new crutch design with two phases: First, identifying crutch design requirements by design-based research. Second, defining market position involving financial analysis. Authors studied forearm and axillary crutches as medical devices and targeted temporary crutch users as target group. With the aim of developing guidelines for a new crutch design, that fulfills user and market needs based on the outcomes of the research.

16.1 Literature Review

Following is a review of literature about the main concepts behind innovative product design.

16.1.1 Creativity, Innovation and New Product Development

Creativity and innovation are fundamental elements to develop new product concepts in engineering and design context. To understand the importance of these concepts and their interrelation, it is necessary to describe them briefly.

Creativity is a result of the idea generation process to form fresh and useful concepts. Dorst and Cross argued that creativity in design could be described as a sudden insight or when a key concept began to emerge during the design process, "it is what keeps a designer from routine behaviour" [12]. According to Heap, "creativity is the synthesis of new ideas and concepts through the radical restructuring and re-association of existing ones" [4, 13].

Innovation proposes the transformation or the implementation of creativity output (new ideas, devices or methods) into new products/services or enhanced products/services that meet user or market needs in a way that distinguishes the firm and hence generate competitive advantage if not monopoly [4, 7, 14]. Furthermore, innovation can be in the process (e.g. new method of production or new source of material) or in the product/service itself (e.g. new product, new quality or new industry structure) [14–16]. Therefore, creativity represents the trigger of the entire innovation process [4, 7, 17].

16.1.2 Design and New Product Development

Previous researches underline the importance of design and design process for the success of the new product development (NPD) [18, 19]. Hsiao and Chou described product design as a goal-directed problem-solving activity [4]. The efficiency and economic value of design in NPD process are indicated in literature; it is mentioned that design-driven NPD provides competitive advantage, evolves technical performance and reduces production costs. Moreover, design orientation in NPD is an effective innovation process that pushes and moves business forward. In addition, literature discussed how inappropriate design could have negative impact on all other product life-cycle phases, and can ultimately result in the failing of the new product, as product design is an integrated process that includes activities that starts from generating ideas until identifying proper product and design solutions [18, 20–22]. In addition, there are some internal factors within firms that directly create competitiveness during innovation and NPD process. The ability to apply new technologies and to invest in research and development activities is among the most significant internal factors that increase the competitive advantage [23].

16.1.3 Research in Medical Device Development and Design

In the World Medical Association Declaration of Helsinki in 2000, 32 ethical statements were developed to guide human subject involved medical researches. According to the basic principles for all medical research, “Medical research involving human subjects must conform to generally scientific knowledge of the scientific literature, other relevant source of information, and on adequate laboratory and, where appropriate, animal experimentation” [24]. Therefore, medical device design is a hard and challenging process that requires effective knowledge, practice and method management between medical, engineering and design experts during the medical design innovation process [8].

According to medical device development literature, users’ perspective has a great importance to analyze and improve user needs. Their involvement in the product development process is required to point out potential problems and deficiencies of existing medical devices. In addition, engagement with users has benefits on medical device development and evaluation through innovation, creativity and technology. The involvement of the user is as important at each level and stage of the NPD process. However, their involvement has a crucial role during the idea generation phases rather than the further phases, such as prototyping and/or testing [25–27].

Additionally, the current literature underlines that both device users and clinicians involvement into the medical device development is crucial. Therefore, valid, safe and usable data collected from their feedbacks in terms of ergonomics and human factors have vital role to guide medical device design process [8, 28].

16.1.4 Walking Aids as Medical Devices

Walking aids are supportive medical devices that are prescribed by medical experts to the patients. The needs for walking aids are various such as "normal ambulation is compromised by pain, impaired balance, weakness, or musculoskeletal abnormality following trauma, surgery, or incapacitating pathology" [29]. In this context, crutches are the most commonly suggested and preferred medical walking aid devices that propose physiological and psychological advantages to people with disabilities. Therefore, many people are using crutches that have different kinds of disabilities or injuries such as "amputees, paraplegics, people with broken bones, people with torn ligaments and many others" [30]. In addition, crutches provide walking aid to mechanical or neurological disability and reducing lower limb stress [31].

According to the biomechanical evaluation of crutch design literature, walking aids like crutches have been used for over 5000 years besides without major changes on their functional properties and forms [31]. Mostly, two basic types of crutches are prescribed that are axillary crutches and forearm crutches. Axillary crutches are also known as underarm crutches. They consist of handgrip and armpit support parts. This type of crutch is generally suggested for short-term usage to the temporary crutch users. Forearm crutches are also known as elbow crutches. They consist of handgrip like axillary crutches, but the top point ends at elbow height. This type of crutch is also suggested for short-term usage to the temporary crutch users [32].

Consequently, the selection of the type of crutch depends on the patient's injury and body type. In this selection, the most important factors are "user's balance, weight-bearing status, and upper limb and trunk strength." In addition to the crutch choice, the education of an efficient gait pattern is crucial for inexperienced crutch users to gain safe and comfortable walking aid mobility [31].

Current literature underlines that axillary and forearm crutches have both advantages and disadvantages in terms of their fundamental characteristics and properties. Some sources state that elbow crutches provide more energy expenditure than axillary crutches. Therefore, they are more safe and comfortable. However, more energy and effort are needed for ambulation with elbow crutches than axillary crutches [32].

In previous researches, some problems caused by current crutch designs are stated. They classified under three main categories that affect directly the human factors and ergonomics. First, the usage of existing crutches demands high-energy expenditure during crutch ambulation and gait [33]. Second, some arm, hand and wrist injuries that caused by repetitive loads on these body parts during ambulation [34]. Third, lack of standing and walking cause some blood circulation and bone growth problems [35].

16.1.5 Market Analysis

Medical industry has slow technological adoption, in contrast to other sectors. Hence, the identified and unidentified challenges of changing marketplace will be subjected to healthcare industry upcoming years [31]. According to the World Bank report, the total health expenditures per person had doubled between 1970 and 2001 in the United States. It was $14.1 trillion and the number increasingly growing. *"In 2009, the United States spent 17.4% of GDP on health, 5 percentage points more than in the next two countries, the Netherlands and France (which allocated 12.0% and 11.8% of their GDP on health)"* [33].

The existing crutches seem like a cheap solution; however, the point of the medical experts explained the problems of posture and joints after usage. According to the World Health Organization (WHO), the medical device should be accessible for each income level. The WHO lists the examples of policies on medical devices [32] in their words as;

- Regulations of medical devices minimize risk to the population.
- Safe use and availability of medical devices improve health service delivery.
- Affordability of medical devices increases health service coverage.
- Telemedicine enhances patient-centered care.
- Health technology assessment provides a basis for priority setting and informed decision-making.
- Needs assessment helps in the rational allocation of resources.
- Research and innovations respond to the needs of a particular health system and population.

On the other hand, sprained ankles and leg injuries are the most frequent health issues around the world [36]. The use of crutches assists the walking with one leg to be mobile. Besides, according to the report of 2013, use of walker is 1.8 million people and use of crutches is 566,000 per day for walking [37].

16.2 Methodology

16.2.1 Research Method

The study is formed as multi-research techniques [38] to collaborate in academy and practice. The process of the study based on multi techniques such as the brainstorming phase- research phase- interview phase- user test phase- financial analysis phase and proposing design phase (Table 16.1).

The study proposes a new walking aid design for temporary user profile on determining the problems on existing crutches. The research aims to find three key factors to propose the new crutch design;

Table 16.1 Process of multiple techniques

Phase	Number of participants	Outcomes
Focus group	Ten participants (one material engineer, two mechanical engineers, six industrial designers and one city and regional planner)	User identity, existing needs
Interview A	Two medical market	Bestseller product, common problems
Interview B	Four medical experts	Medical problems after usage
Online survey	Five crutch users	Problem definition of existing product
User test	Two participants (testing existing forearm and axillary crutches in the market)	Practice-based problems
Financial analysis	Three scenario-based analysis	To analyze the potential market price by focusing on the accessibility of the product

- Analysis of usage problems.
- Analysis of post-usage problems.
- Financial analysis.

The method of inquiry starts with understanding from different perspectives on the product for generalization and development of insights. Therefore, the research continued with preparing survey through the elements of the demands of the individuals from three different perspectives.

First application is to define the problem on existing crutches. The data is collected from several sources as medical market owner, user and medical expert by interviews. The main focus of the interviews is to generate a list of design requirements.

Second application, which is financial analysis with three economic scenarios, is conducted to determine the position on the market and material, technological properties of the product.

The data are collected to list the product specifications. In other words, in this study, filter of the consumer perspective, medical expert and seller with three economic scenarios create the design requirements.

16.2.2 Focus Group

The phase is applied to focus on the product regarding the new product design. Ten designers generate the ideas through the observation. According to the discussion, the following user needs were determined and were shown below;

- Self-standing function for the crutches.
- Unaided sit-down and stand up.

- Hands-free usage.
- Easy storage.
- Skid-proof.
- Light-weight.

16.2.3 Interviews

We conducted semi-structured interview with random sampling for medical market to analyze the consumer preferences, product features and types. After exploring which types are suggested for our target user, we applied user test on axillary crutches and forearm crutches. In that phase, we recorded to camera, took the pictures and took notes.

Through the interview with medical market, we carried out semi-structured, open-ended survey and unstructured interview on crutches with four medical experts face to face, on phone and through internet. At the same time, semi-structured survey with open-ended questions are asked to define users' needs and problems on internet. The snowball sampling is applied to reach the participants. Four male and one female answered the questions.

16.2.4 User Test

After exploring which types are suggested for the target user, a user test on axillary crutches and forearm crutches was applied. In that phase, the user test videos were recorded and the usage pictures were taken by digital camera and interview dialogue was noted for documentation.

The most commonly preferred types of crutches, which are the axillary crutches, and the forearm crutches were tested and examined as shown in Figs. 16.1 and 16.2.

Two participant-involved user test was applied to search and define the problems of first-time user experience. The participants were at the age of 26 and 29 inexperienced crutch user. Scenario-based analysis is applied as the participants were asked to walk during 5 min on the marble floor of the store and sit down, stand up on a chair without any help. The interior of a medical store was chosen for the user test settings.

16.2.5 Market Analysis

There are two types of crutches for temporary usages, such as forearm crutches and armpit crutches on the medical markets. The producers vary the crutches by material like wood and plastic handles and color options with same form. In medical market,

Fig. 16.1 Axillary crutches

Fig. 16.2 Forearm crutches

the existing function, there are many competitors. The price is changing from 20 to 500 dollars. The other competitors are not on the market. Some brands or design groups work as a concept within the same concept with us which body raise aid, stair ascent or arm elbow support with a different form. However, these products are more expensive than our product [39].

Table 16.2 conducted to analyze the marketplace through visual analysis and user experiences through the internet. The proposed design requirements created to alternate and innovate, the existing solutions.

Table 16.2 Analysis of selected solutions

Product		*I-Walk [40]*	*Ergobaum Forearm Crutches [41]*	*S_Upport [42]*	*Hurricane [43]*	*Freedom Leg [44]*	*X Crutches [45]*	*Smart Crutch [45]*	*Proposed*
Target		Average Strength Body Type	Long-term short-term users	Short-term users	Short-term users	Short-term users	users from 130 cm (4.2 ft) to 190 cm (6.2 ft) tall.	Long-term short-term users	Short-term users
Symptom	*Below the knee injuries*	***	*****	**	**	****	****	****	*****
	Full leg Injuries	*	*****	**	***	**	***	****	*****
Stair Ascend		*	**	*	*	****	****	***	*****
Hands Free		*****	*****	*	**	*****	***	****	*****
Body-Raise Aid		*	**	**	*	*	*	*	*****
Knee-rest		*****	***	*	*	****	**	**	**
Forearm rest		*****	*****	*	**	*****	****	*****	*****
Adjustable		**	*****	*	**	****	****	****	*****
Storage Advantage		*	*	*	**	*	*****	**	*****
Arm Elbow support			***	*	***		***	***	*****
Anti Slip Tip		*	*****	*****	**	***	*****	****	*****
Shock Absorber Tip		**	*****	**	*	***	****	**	*****
Light weight material		*	**	****	*****	**	***	***	****

(continued)

Table 16.2 (continued)

Product	*I-Walk [40]*	*Ergobaum Forearm Crutches [41]*	*S_Upport [42]*	*Hurricane [43]*	*Freedom Leg [44]*	*X Crutches [45]*	*Smart Crutch [45]*	*Proposed*
After Use Problems	Pressure on the Knee	Pressure on the wrist	Pressure on the wrist	Pressure on the wrist	Pressure on the Knee	Pressure on upper leg and quad muscles	Pressure on armpit	
Self Standing	*	*	*	*	*	*	*	*****
Body-object adaptation	**	****	***	*	**	**	***	****
Ergonomics	**	*****	****	***	***	**	*****	*****
Additional solution	knee stabilized ninety-degree	unique ergonomic orthopedic devices	Reuse material	Provides upper body strength	Light weight	convenient storage, Light weight	provides greater stability	Weight balance
Price (two pairs)	149 $	200 $	Not in sale	140 $	499 $	240 $	206 $	100 $ -20 $
Economical Performance	***	***		***	*	**	**	*****
Production Performance	**	****	**	***	**	*****	*****	*****

weak * ** *** **** ***** strong

16.2.6 Financial Analysis

In this part, the financial analysis based on three scenarios including the demand potential and the technology is mentioned.

The first scenario is created for the Turkish market. The demand is taken as 22.000, regarding the US percentage [37]. In that scenario, the cost/price balance is measured to compare with the existing crutches. The investment would be higher in the beginning and there is no expansion investment. Besides, the price of each crutch will not be able to expensive and will be affordable for each level income society. The gross income is the lowest because it could be the encouragement of government or a project with the collaboration between university and producer.

The second scenario starts with minimum investment and less demand with a high technology and higher price to increase the gross income. In this scenario, the limited crutches could be in the market with higher price.

The third scenario is concreted as same investment as first scenario with doubled cost and price, oppose to first scenario the expansion investment added with higher demand. The reason behind that is the advertisement, logistic and the other service costs would be more in that scenario to access the people (Table 16.3).

16.3 Results

16.3.1 Focus Group Results

The phase is applied to focus on the product regarding the new product design. Ten participants generate the ideas through the observation. According to the discussion, the following user needs were determined and were shown below;

- Self-standing function for the crutches.
- Unaided sit-down and stand up.
- Hands free usage.
- Easy storage.
- Skid-proof.
- Light weight.

16.3.2 Survey Results

In this study, the semi-structured open-ended survey was applied on internet to the users of crutches to understanding user's perspective. In addition, the semi-structured, open-ended survey on crutches was carried out with two medical experts through internet.

Table 16.3 Summary cash flow

		Annual interest rate = 5%												
	IRR	Gross	Year 0	Year 1			Year 2			Year 3 expansion	Year 3.10		
Icenano	(%)	income	Investment	uCost	uPrice	Demand	Cost	Price	Demand	investment	Cost	Price	Demand
1	14	409,000 €	400,000 €	10 €	12 €	22,000	11 €	13€	22,500	0 €	14 €	17 €	30,000
2	68	833,000 €	100,000 €	50 €	60 €	6,000	53 €	64 €	7,000	100,000 €	70 €	84 €	8,000
3	76	5,980,000 €	400,000 €	20 €	24 €	30,000	20 €	24 €	40,000	300,000 €	40 €	48 €	100,000

The main problem of existing crutches is the lack of self-standing function. In other words, the problem occurs during the sitting time of user on a sitting unit. Because crutches mostly fall over when they are not in use. Second, because of the lack of body and weight support the user has difficulties of sitting and standing while using the crutches. Third, the user does not have opportunity to use his/her hands while standing with the crutches. The last problem is the storage difficulty of the crutches while getting on a vehicle with them.

The user profile chosen for the study is the adults (20–40 ages) people who have broken legs or have ankle/knee injuries. In other words, the target is the temporary user of the crutches. The study aims to provide the user to stand up easier with the assistant help of the crutches. Besides, they should allow hands-free usage to the user. On the other hand, the study should focus on the storage functions of the crutches.

16.3.3 Crutch Users' Perspective

The participants vary between the ages of 20 and 30. In total, five users of crutches had answered the online survey. In addition, 80% of the participants are male and 20% of them are female.

According to the answers of the participants, 60% of them used forearm crutches and 40% of them used armpit crutches. The following answers of the participants are listed below.

- The use period of the crutches changes between 1 and 2 months.
- The purpose of uses are for broken legs or ankles and knee injuries.
- The most wearing parts of crutches are;
  - Handles
  - Tips
  - Adjustment holes
  - Elbow supports
- The usage problems on different surfaces are;
  - Slippery surfaces
  - Sloping surfaces
- The difficulties facing during sitting and standing are;
  - The storage problem of crutches while sitting and the need of aid for standing.
  - The need of extra force for standing up.
  - The lack of different level or angled handles for standing up.
  - The height problem of the crutches that enforce the standing up.
  - The feelings of insecurity while standing.
- The most common difficulties on usage of crutches are;

  - Self-standing
  - Unaided sit-down and stand up
  - Hands free usage
  - Storage
  - Skid-proof
  - Weight and height adjustment
  - Customization
  - Durability and resistance
  - Life cycle
  - Ergonomics
  - Affordability
  - Interrelation with public spaces, furniture and so on

- Other health problems occurred by crutch usage are;
  - Hygiene problems
  - Skin scratchiness
  - Blisters in palm and armpit

- The requested extra functions and needs for crutches are;
  - Handle should be closer to the ground.
  - Crutches may have tripod legs.
  - One crutch could be tripod, the other could be standard.
  - Ease of store, hang, put and so on.
  - Foldable.
  - Comfortable, soft and ergonomic handle grips.
  - Changeable tips for hygiene.
  - Center of mass should be considered.
  - Hands-free usage to carry bag, phone usage, drinking, exchange, and so on.

16.3.4 Medical Experts' Perspective

The participants are both the profession of the doctor; however, their expertise areas are different. According to the answers of the participants, crutches are supportive medical equipment, which provides mobility and benefit to the patients. Besides, they may prevent arthritis in joints. However, some problems may occur on prolonged use of the crutches.

- The health problems may occur are;
  - Joints get lazy.
  - Creates posture disorders.
  - Damaging armpit and knee that the weight is carried by.

- The additional comments and suggestions of medical experts are;
  - Being soft does not always mean it is comfortable for handles or other parts of the crutches.
  - Height should be adjustable for handles and armpit parts.

16.3.5 Interview and User Test Results

The medical store interview results are listed below;

- Tripod crutches are not useful for walking, they generally hit to the user's leg.
- Wooden crutches are heavy, therefore they have less demand.
- Plastic crutches are washable and light; however, they have short life cycle.

According to the user test experiences and results, two body image illustrations were prepared to emphasize the user perspective. Body parts marked with red color are showing where the pressure and pain felt caused by crutches. The muscle groups marked with blue color are showing which are strained and sore. In Fig. 16.3 axillary crutches and in Fig. 16.4 forearm crutches user experiences are shown.

16.3.6 Proposed Design

In this part, the product attributes and detailed specifications of the proposed new crutch design are mentioned in accordance with the collected information and data during the research. The proposed new crutch design serves to the user needs

Fig. 16.3 Axillary crutches user experiences

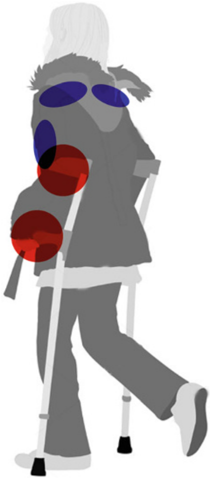

Fig. 16.4 Forearm crutches user experiences

collecting through the research, which are body-raise aid, stair ascent, arm-elbow support and self-standing functions. In this context, the material, dimensional and functional characteristics of the new product are listed in the following table (Table 16.4).

The proposed new crutch design and its specifications are mentioned under the four categories in the product specification table. Additionally, the draft design sketches of the proposed new crutch design are shown in detail in Figs. 16.5 and 16.6.

16.4 Conclusion

Temporary crutch users are patients who do not have physical possibility to use crutches because of the leisured muscle condition. The existing crutches cause some medical problems, which our product aims to solve. Therefore, to avoid the medical problems after using crutches, our product ensures balance the body weight, skid-proof for slippery floor and it is body-raise-aid for sitting/standing easily. It is created after taking the view of medical experts that makes our product reliable.

Our product conducted with design through research, which offers advantages not only to market, but also to the academy to develop the product with both perspectives. The practice-based system is concreted from the user perspective and medical expert perspective with a user test. The problems of the existing

Table 16.4 Product specifications

Specifications	
Size	1.0–1.5 m
Type	Forearm crutch
Material/s	Carbon fiber reinforced composite, thermoplastic, carbon fiber reinforced polymer, aluminum alloy, silicone rubber
Parts	
Handle/grip	Yes (adjustable and replaceable)
Arm-elbow support	Yes (cushioned and adjustable)
Wearable elbow strap	Yes (adjustable)
Crutch tube	Yes (graduable silenced tubing)
Crutch tip	Yes (360° rotation)
Functions	
Body-raise aid	Yes
Stair ascent	Yes
Arm-elbow support	Yes
Self-standing	Yes
Additional features	
Foldable body	–
Adjustable height	–
Adjustable angle grip	–
Shock absorber tip	–
Silicone grip	–
Skid proof-replaceable tip	–
Waterproof material	–
Cleanable material	–
Long lifetime	–

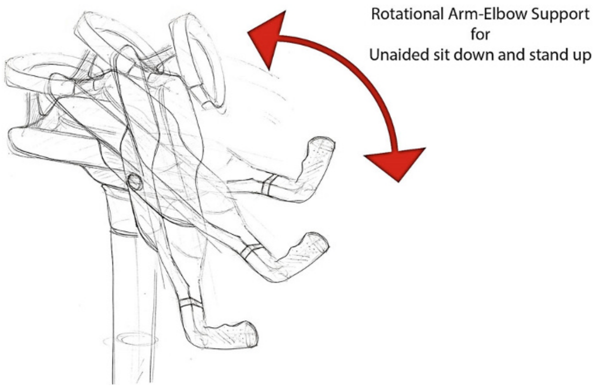

Fig. 16.5 New crutch design details

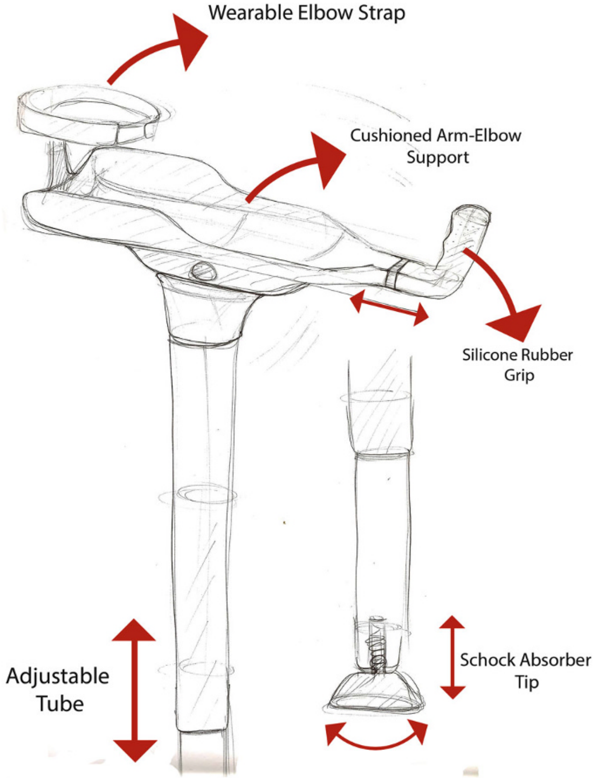

Fig. 16.6 New crutch design details and specifications

crutches solved with body-raised aid, skid-proof and storage opportunity with three economic scenarios. The crutches would be cheaper than the competitor even it is innovative because we believe that the medical products should be accessible to every level of income society and it has short-term usage.

The draft design of the proposed new walking aid addresses some of the needs expressed by permanent crutch users. Its cushioned and replaceable arm-elbow support design gives added support and comfort. Also, it provides body-raise aid and stair ascent to the user. The adjustable and replaceable grip assists a good and comfortable grip at different angles. The adjustable and wearable elbow strap and skid-proof replaceable tips ensure a safe use.

However, the proposed design improvements that discussed above need to be implemented and tested with a prototype. There are potential benefits in this study through further refinements for the permanent crutch users.

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Part IV
Commercialization of Technological Innovations

Introduction

The road to the commercialization of technological innovations is filled with obstacles. In order to surpass those obstacles, one needs to understand them and have processes in place with proper methods and enough organizational support. This part of the book focuses on identifying and understanding the obstacles, and also focuses on the development and application of a technology transfer process that enables managers to succeed in commercializing the outcomes of technology research and development projects. This part is divided into four chapters (Chaps. 17–20).

Chapter 17—“Technology Transfer: A Literature Review”—lays the groundwork for the development of a technology transfer process. It dives into the literature bringing general information about the body of knowledge in the field, touching upon the relationship between technology transfer and related fields.

Chapter 18—“Technology Transfer Assessment: An Integrated Approach”—presents and discusses a novel methodological approach to technology transfer issues, acknowledging that those are multifaceted, complex, and multidisciplinary. It proposes using Hierarchical Decision Modeling (HDM) aided by Action Research, in a combination that aims at extracting the best of academic research and practitioners’ experience.

Chapter 19—“Evaluating Technology Transfer: Case of a Power Utility”—applies the previously presented methodology to a large US Federal Agency within the energy sector. It presents the action research in detail, as well as the model building, application, and results. This chapter brings an in-depth case study and serves as a starting point for discussions on how to improve the method.

Lastly, Chap. 20—“Technology Licensing Performance and Strategy of US Research Institutions”—focuses on technological development in Universities and research centers, presents a method to evaluate their performance in terms of successfully transferring their research outcomes, and brings strategic recommendations on how those institutions could improve their performance.

We sincerely hope you enjoy the reading and find it useful and insightful.

Cheers,
João Ricardo Lavoie

Chapter 17
Technology Transfer: A Literature Review

João Ricardo Lavoie and Tuğrul Daim

17.1 Introduction

With global economic dynamics and customers demanding better products and services, organizations regard innovation as a critical component of their businesses, regardless of the sector they compete on. Innovation, in turn, can be translated into more and better processes and products that minimize costs and that fulfill the ever-increasing and ever-more complex requirements and expectations of consumers. Having this scenario in mind, research and development (R&D) activities become more and more crucial since the innovation that organizations need spans largely from these activities. R&D, once seen as a purely creative and non-manageable process, has started to attract the attention of managers who see an opportunity to enhance innovation and the whole performance of an organization by means of managing research and development efforts. In that context, many managerial processes have been created and advanced, among which one can mention project management, program and portfolio management, new product development, and road mapping, among others.

Technology transfer (TT) is one of those processes, and although it has been subject of research for at least 45 years, it is still a very unclear process and presents several research opportunities. Technology transfer is a multi-faceted process [1]. It is a very complex problem that involves multiple perspectives and disciplines [2–4]. Notwithstanding being less mentioned than other managerial processes when it comes to enhancing R&D performance and overall organizational performance, technology transfer plays a critical role especially for high technology organizations. According to several authors, an organization with good technology transfer

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capabilities has a competitive advantage over rivals, bringing better products and solutions to the market, faster, and more easily [5–7]. Once regarded as a one-time event to be carried out after a technology is completely developed, technology transfer has evolved to be much more than simply deploying or transferring a technology after it is fully developed. It is a crucial process that runs in parallel with technology development and can affect its outcomes. In 1976, Robbins and Milliken were already regarding TT as part of the innovation process. The consensus now is that this process should be properly managed, if it is to result in benefits to the organization [8, 9]. The importance of technology transfer is easily identified in the literature, but more than only the transfer itself, the process, and how it is managed is also very important. To have a proper TT process in place is vital. Magnusson and Johansson [9] explain that, for any transfer to be successful, not only do organizations need to be aware of what is going to be transferred and when, but also how the process is being conducted [9].

The objective of this chapter is to provide information about the body of literature on technology transfer, thus helping researchers and practitioners in obtaining an understanding of the field. Basic concepts, ideas, and dimensions of technology transfer are presented and discussed, and the borders of the filed are stretched in order to provide insights on how technology transfer interacts with other areas.

17.2 The Technology Transfer Literature

17.2.1 Technology Transfer Definitions

Technology transfer is a multidisciplinary effort, not quite comprehensively understood and carried out by organizations in general. This apparent fuzzy description of TT is also (and not by occasion) seen in academia. The very definition of technology transfer can be confusing and emanate different interpretations. Several different definitions are observed across the literature, each with slightly different perspectives and nuances. Although these definitions have common points and do not seem (at least not for the most part) to be diametrically opposed to each other, this plurality of definitions can be troublesome and harm practitioners in their pursuit of effective, smoother, faster, and more efficient technology transfer. As academia is always at the forefront of knowledge creation, therefore, scholars still need to come to a consensus on what is the best definition for technology transfer, or what are the best definitions, depending on the type of transfer, type of organization, purpose, and other factors.

For Zhao and Reisman [10], the definition would change according to the discipline or knowledge field [10]:

- Economy: the focus would be on technology production and design.
- Sociology: the focus would be on social aspects.
- Anthropology: the focus would be on cultural change.

In the early days of TT research, Bar-Zakay stated that technology transfer happens when a technology generated on one context is used in another one [2]. More recently, it was defined as bringing technical expertise from one organizational reality to another [3]. Heinzl et al. [11] bring the concept of commercialization into scene when they state that TT is the “process of developing practical applications for the results of scientific research,” and the “process of moving technology from an institution of science base to an industrial organization, which successfully commercializes the technology” [11]. Also focusing on commercialization aspects but including a technology diffusion element, Meseri and Maitai [12] state that “technology transfer is a complex process, involving the diffusion of basic research and its ultimate commercialization” [12]. Following the same line, Rogers et al. [13] argue that it is moving a technology from a research organization to a receiver. The process is complete when the transferred technology is commercialized and sold in the market as a product [13]. Focusing more on the geographical aspect, Liu [14] defines it as transferring technologies from one organization or location to another [14]. Bringing the terminology of mechanisms, Amesse and Cohendet [15] argue that TT happens when people or organizations, using different mechanisms, come together and interact to interchange technologies [15].

In summary, technology transfer will always involve the movement of knowledge (and sometimes physical items) to be used, further developed, or commercialized by another set of people, be it within the same firm, across different organizations, or even different countries. The specifics of the process will vary significantly depending on the type and purpose of transfer.

17.2.2 TT General Characteristics

Technology transfer is a complex process. It requires an interdisciplinary approach [2, 16] and it is a multi-faceted process, not a simple one [1]. Instead of being passive in serving only as an auxiliary process for other managerial processes (e.g., project management), it has to give information that will help managers make decisions and take actions. The TT process involves “go/no-go” decision points [2].

According to Seaton and Cordey-Hayes [17], the requirements for an organization to conduct a technology transfer are:

- Technical functions should support the business priorities the organization has set and create new opportunities based on these priorities.
- All functions should be integrated in order for the organization to work as a network (with internal and external connections).
- Employees and managers should be educated on how the organization and the process work.

Bar-Zakay [2] has dealt with the questions of the skills required for technology transfer. The author argues that, for both sides (donor and receiver), these skills are essential: System analysis; technological forecasting; long-range planning; and project-related intelligence [2].

The question of success factors has also been dealt with in the literature. In order to be successful, TT requires the development of technology markets and the development of technology valuation methods [18]. Leonard-Barton and Sinha [19] highlighted two important factors for a successful technology transfer. The authors discuss how organizations have to undertake an adaptation process (either for the new technology to be adapted to the organizational environment, or the other way around), and how the communication and interaction between developers and users should be very clear from day one [19]. Franza and Grant [20] have listed success attributes by player types, namely the developer, the acquirer, and both, showing the traits and characteristics each group ought to have in order to thrive.

In a very comprehensive research work, Estep [21] identified technology transfer success attributes, perspectives, and factors that fall into four categories: research domain; technology recipient domain; technology characteristics; and interface strategy, as shown in Fig. 17.1 [6].

Previous studies have also tried to identify and define the stages contained in a technology transfer process. According to the framework developed by Bar-Zakay in 1971, technology transfer would contain four stages: Search—when one searches for technologies to be transferred; adaptation—when one adopts the technology and the organization for them to work together; implementation—when one does the actual transfer and deploys it in the new environment; maintenance—when one makes sure the technology is and will work properly in the long-run [2]. In a

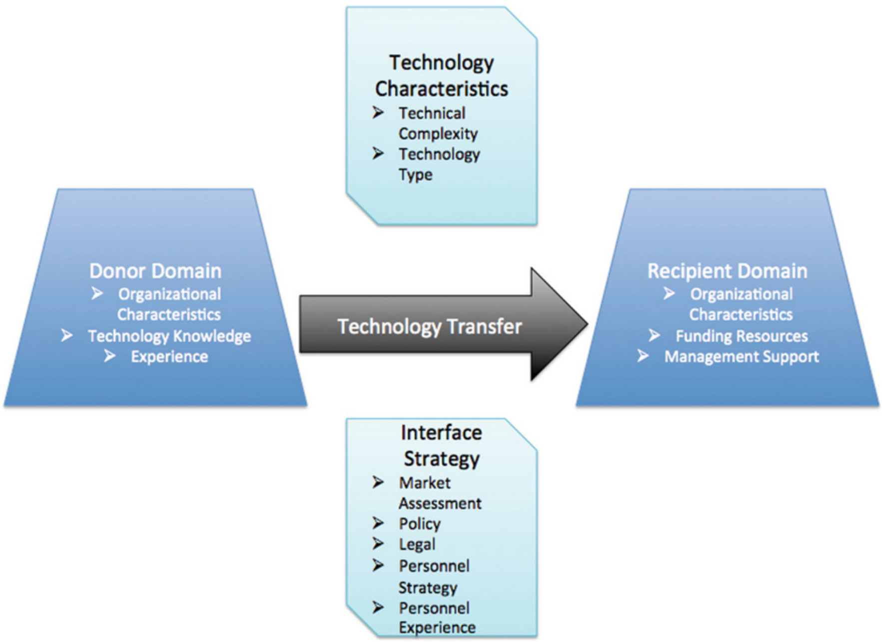

Fig. 17.1 TT success attributes perspectives, adapted from [6]

more simplistic fashion, Seaton and Cordey-Hayes have stated that the TT stages are ideas scanning, communication, and assimilation within the organization, and idea application with a purpose, which would be higher business effectiveness or competitive advantage [17].

Some studies were conducted with the aim of delineating the TT process and the elements or factors involved in the process. For Heinzl et al. [11], the important factors for technology transfer are: transfer object; transfer mechanism; intellectual property (IP) rights; absorptive capacity; and support structures [11]. Transfer object is the "what," it is the item or element to be transferred from the donor to the receiver. The mechanism is the "how" the way or the vehicle through which the transfer is conducted. IP rights comprise all legal considerations over patents, brand, trademarks, and other intellectual property aspects. Absorptive capacity refers to the skills of an entity of receiving, understanding, and properly using new information and knowledge [22]. The support structures are organizational arrangements and entities that provide aid and assist the transfer process. The Technology Transfer Office (TTO) at a university would be a good example [11]. Nobelius [1] lists three elements of the TT process: Strategic and operational synchronization; transfer scope; and transfer management [1]. The first part refers to the alignment between research and technology development efforts and the overall business strategy and application. The second part refers to the transfer object. The third and last part refers to the mechanism and the technology transfer process itself and how to manage it. Bozeman [3] also dealt with specific dimensions of effectiveness for TT. The author lists as important dimensions: transfer agent; transfer medium; transfer object; transfer recipient; and demand environment [3].

The literature also provides more specific criteria that should be assessed during a transfer, or questions that should be posed in order to measure the transferability of an item or to measure the potential for transfer. Both qualitative and quantitative criteria are mentioned as vital to assessing technology transfer aspects. In his 1977 article, Bar-Zakay lists two sets of criteria/questions to be checked on the donor and the recipient side. The questions relate to the number of people involved, training, interaction, planning aspects, and complexity of transfer, among others [16]. Bozeman [3] lists as important criteria: out-the-door; market impact; economic development; political reward; opportunity costs; and scientific and technical human capital [3]. Out-the-door would relate to the question whether technology has actually been received by another party. Market impact relates to the question of profitability and market-share changes caused by the transfer. Economic development relates to market impact questions on a regional or country level. Political reward relates to political gains derives from the transfer, such as more and better access to funding. Opportunity costs relate to other uses for resources or other agents and items. Scientific and technical human capital relates to the impact and advancements to technical skills and infrastructure caused by the transfer. Heinzl et al. [11] provide three categories each of which with associated factors and dimensions needs to be taken into account: providing agent; receiving agent; and environment [11]. Baek et al. [18] also list specific criteria. On the qualitative side, the author lists the analysis of technology's degree of contribution. On the quantitative side, the author lists the analysis of expected returns, cost structure estimation, and market estimation [18].

Technology transfer, although it can be strictly confined to the boundaries of one organization (when it is an internal TT), usually involves two or more entities. Moreover, even if it is an internal process, it will certainly involve several different groups and departments. The collection of these entities is commonly referred to as the technology transfer ecosystem. A TT ecosystem is a collection of stakeholders and entities (a system) that work together to promote a better transfer and to create value. Meseri and Maital [12] argue that a systems approach is essential for technology transfer [12]. Some of the entities mentioned are: science parks; research centers; incubators; TTO’s; innovation and commercialization networks; and proof of concept centers (POC) [11]. The technology transfer offices (TTO) are also mentioned in other studies [23, 24].

17.2.3 TT Types

Several types of technology transfer are mentioned and studied in the literature. Table 17.1 shows the most recurrent ones.

The succinct definitions of each type are as follows:

- Internal—intra-firm transfer; the process occurs within the same organization.
- External—the transfer occurs between different organizations, regardless of their locations.
- Domestic—the transfer occurs within the same country.
- International—the transfer occurs between different countries.
- Military to civilian—military technologies to be transferred to civilian usage/ private companies.
- National labs to private sector—technologies developed within federal labs to be commercialized by private companies.
- Universities to private sector—technologies developed within Universities to be commercialized by private companies.

Table 17.1 Technology transfer types

Type	References
Internal	[14, 22, 25]
External	[2, 14, 16, 18, 25]
Domestic	[3]
International	[2, 25–32]
Military to civilian	[16]
National labs to private sector	[3, 13, 20, 33, 34]
Universities to private sector	[3, 11–13, 35, 36]
Research to development	[33]

- Research to development—the transfer from the technology development process into the product development process. Also involves the transfer of technologies in its early stages of development.

The above list brings the most recurrently mentioned TT types in the literature, but it is not exhaustive. Furthermore, these types are not mutually exclusive, as a transfer might fall into two or more types, for example, an American company may transfer a technology from a university in the UK to be used in one of its business units in America. In that case, the transfer would be external (different entities involved), from a university to the private sector and in the international realm. Within this list of TT types we provided, the University technology transfer is, perhaps, the type scholars investigate the most. The following section brings a more detailed discussion about university technology transfer.

17.2.3.1 University Technology Transfer

University technology transfer, especially from an economic and country development standpoint, is very important. According to Heinzl et al. [11], universities are vital to the national innovation system, because they provide diverse and high-quality knowledge while disseminating good practices, know-how, and competency [11]. The author further states that a more efficient technology transfer process from universities would mean more jobs and wealth for its region and country [11]. Previous studies have tried to identify the steps involved in the process of transferring technologies from universities [13, 36]. The models depict the disclosure of the invention made in academia, followed by the protection of the intellectual rights. Also, they include the reach out effort to interested parties and the negotiation to transfer, and the appropriate mechanism to do so.

Chen et al. [35] summarize the main themes in the literature when it comes to university TT: government policy and national innovation systems; university-operated enterprises; university science parks and spin-offs; university-industry linkages; TTO's; and university patenting and licensing [35]. In 1991, during the rise of technology transfer offices (TTOs), Mitchell noticed a change in how universities dealt with technology transfer [37]. In 1998, however, Mejia was arguing that the majority of transfers from universities were still done by publications, and a stronger linkage between universities and industry was needed [23]. In another comprehensive study on university technology transfer, Siegel et al. [36] create a series of propositions after analyzing the literature, pointing on characteristics and challenges, such as providing more rewards for researchers; providing more and better resources for TTO's; changing the mentality of university researchers; management and marketing efforts on TTO's; more flexibility on the university's side; and more formal and constant interactions between industries and universities [36].

17.2.4 TT Mechanisms

As already mentioned, a mechanism is the vehicle used to transfer the technology. Table 17.2 lists the most mentioned TT mechanisms in the literature:

Contract research is a contractual arrangement between the technology developer and the technology recipient. It sets the basics of the transfer, such as who is involved, what will be transferred, and how [11]. Foreign direct investments (FDI) are when an organization makes an investment through purchasing another organization in a foreign country. According to de la Tour [30], FDI in developing countries are "... carried out to benefit of cheap labor, they hire local work-force to which the know-how is then transferred" [30]. Further development happens when a technology is not completely ready yet, and follow-up research is needed. Also, further development is necessary when a technology is not significant enough for the industry to be willing to deploy it, or when the technology does not result in competitive advantage for the organization [38]. Transfer by internal start-ups happens when a technology generated within an existing organization is explored by a new company with relative independence from the original organization. According to Festel [38], internal start-ups would be fast and flexible enough to speed up the transfer process [38]. Joint venture R&D happens when two or more organizations share the costs, risks, and potential benefits of a technology development project. Seaton and Cordey-Hayes [17] argue that joint-venture R&D efforts have the ability to lower the risks of development and make the transfer less painful [17]. Licensing happens when an organization authorizes another to use and/or commercialize a technology, without transferring the ownership, which usually involves the payment of license fees. According to de la Tour [30], licensing is the most obvious mechanism of technology transfer [30]. Meetings can be used as a mechanism to pass information along to other parties. As Rogers et al. [13] put

Table 17.2 TT mechanisms

Mechanisms	Reference
Contract research	[11]
Foreign direct investment (FDI)	[30]
Further development	[38]
Internal start-ups	[38]
Joint-venture R&D	[11, 13, 17]
Licensing	[11, 13, 30]
Meetings	[13]
Mobility scheme	[11]
Monitoring of activities of the science base	[11]
Movement of personnel	[30]
Publications	[13]
Regional technology centers	[17]
Reverse engineering	[30]
Science parks	[17]
Spin-offs	[11, 13]

it, “meetings involve person-to-person interaction thought which technical information is exchanged” [13]. A mobility scheme is comprised of the movement of people and this movement can be temporary. Heinzl et al. [11] mention some of these movements, such as professors during sabbaticals; summer internships; and the temporary movement of personnel within and between organizations [11]. Monitoring science-based activities happens when an organization is attentive to the flow of knowledge in its field. Searches on academic article and patents databases, participation in conferences, and industry forums would be some of the activities involved [11]. Movement of personnel is very similar to the mobility scheme in that it involves sending workers along with the technology in order to ease the transfer, and these movements may not be temporary, as in the case of mobility schemes. De La tour [30] argues that these movements can be essential for a successful transfer [30]. Publications in journal and magazines are a way of transferring knowledge and technology and are intensely used in academia. However, although it is common in university transfers, Rogers et al. [13] caution that this is not the best mechanism for transfer, as usually articles are written in language following academic standards and not very easily understood by practitioners [13]. Regional technology centers are, according to Seaton and Cordey-Hayes [17] used in the UK as a mid-point between technology donors and recipients. These entities have a database of technologies available for transfer and help the involved in the process by aiming to improve the success of the transfer [17]. Reverse engineering consists in analyzing a product or technology in its final form and trying to understand its components and sub-systems. De la Tour [30] suggests reverse engineering as a transfer mechanism for companies that import products [30]. Science parks and incubators support and protect start-ups in their initial stages. Seaton and Cordey-Hayes [17] argue that by providing this support, science parks would help in the transfer of technologies [17]. Spin-offs are usually referred to as companies that are born out of universities. In this situation, professors and/or students decide to explore their inventions on their own, as a company [11].

17.2.5 TT Methods

Both quantitative and qualitative methods are found in the literature. Quantitative methods would include methods and tools focusing on mathematical and statistical models, plus multi-criteria decision-making models (MCDM) involve quantitative aspects, such as analytical hierarchy process (AHP) and hierarchical decision model (HDM). According to Khabiri et al. [31], qualitative methods define activities of those who are involved in the process and elicit factors and issues that may influence the success and effectiveness of a TT project. On the other hand, quantitative methods would quantify parameters and analyze them. Also, they try to minimize incompatibilities between donors and recipients [31].

Table 17.3 summarizes some of the sources found in the literature that use and/or mention methods for technology transfer.

Table 17.3 TT method types

Type	References
Quantitative	[6, 14, 18, 20, 29, 34, 39–42]
Qualitative	[2–4, 7, 11, 12, 16, 17, 22, 25, 32, 36]

Table 17.4 TT methods and tools

Method	Type	Reference
AHP	Quantitative	[42, 43]
Decision-model	Qualitative	[2, 11, 16]
Fuzzy-set theory	Quantitative	[42]
HDM	Quantitative	[6, 21]
Interviews	Qualitative	[36]
Mathematical models	Quantitative	[39, 41]
Other types of MCDM	Qualitative	[3, 4, 7, 17, 22, 25]
Nonlinear differential equation	Quantitative	[14]
Scenario analysis	Qualitative	[14]
Maturity scale	Qualitative	[43]
Social network analysis	Qualitative	[44]

Table 17.4 summarizes some of the sources found in the literature that use and/or mention specific methods and tools for technology transfer.

As it can be seen in Table 17.4, subjective models are, by far, the most dominant way of dealing with technology transfer. Within the subjective models, multi-criteria decision-making (MCDM) methods are used. As aforementioned, technology transfer is a complex, multi-faceted, and multidisciplinary effort. As such, it seems that MCDM models are the most appropriate method since they can approach the problem from several different perspectives at the same time. AHP [42, 43] and HDM [6, 21] are not the only models used. There are also decision models based on donor/recipient criteria [2, 11, 16]; manufacturing strategy [25]; contingent effectiveness [3, 7]; broadcasting [22]; multi constituency [17]; and climate-friendly technology transfer [4].

17.2.6 TT Application Areas

Technology transfer models developed in the literature have been applied to a myriad of sectors, from nanotechnologies to aerospace. Table 17.5 brings a list of some of the application areas found in the literature.

Table 17.5 Technology transfer application areas

Area	References
Aerospace	[14]
Climate change	[40, 45]
Construction	[29]
Electric components	[22]
Energy	[4, 6, 30, 32, 46]
Information technology (IT)	[27, 39]
Nanotechnologies	[7]
Semiconductors	[28]
Steel production	[47]

17.2.7 TT Complexities, Challenges, and Gaps

Technology transfer, although having been subject of research for over 45 years, still presents a fair share of challenges to both practitioners and researchers due to its fuzziness and complexity. It is still unclear how to deal with the process and how to manage and conduct it in a proper way. Festel [38] mentions the research gap that exists in the transfer of research and development outcomes to the successful commercialization of those outcomes [38]. As it was discussed, the very definition of TT is not consensual as it varies significantly from discipline to discipline. According to Bozeman [3], TT involves a very large set of players, activities, and interests, making it burdensome [3]. Still, according to the same author, TT is a very complex and risky process. It is very time consuming and usually does not produce the expected results [3]. It is not clear where and when TT starts and ends and concepts like prototypes and proof of concept are not clear either. Most of the time, prototypes are developed without any concern for user requirements and yet they are used as a basis for the final product [33]. Literature suggests the technology transfer process and efforts are challenging and it also suggests that organizations should strongly support and care about the process should they want to obtain good results. Isaacs and Tang [33] say that TT is a contact sport. The transfer is done by people, not by materials or reports. There should be a high commitment and support for the TT process [33].

Concerning university technology transfer, Landry et al. [24] perceive a research gap to be filled. The authors argue that when it comes to TTOs, there is a need to conduct a demand-side perspective study to understand how TTOs' clients perceive those organizations [24]. Some of the questions would be: Do they appreciate the TTOs services? What do they like or dislike about it? How can TTOs be more helpful and effective?

As for the internal technology transfer type, some authors also identify a need for further investigation and research. Malik [22] states that more studies should be done on intra-firm TT to understand it since the majority of research is done on international and external transfer processes [22]. Magnusson and Johansson [9] also argue that more research on internal technology transfer is needed [9].

17.2.8 TT Relationship with Other Fields and Concepts

By analyzing the literature, one can clearly notice that technology transfer, as a field, overlaps with several other fields and concepts. The following sections shed a light on those overlaps and explain how these interactions happen.

17.2.8.1 Relationship with Commercialization

To the vast majority of scholars, technology transfer is intimately related to the concept of commercialization. In the context of TT, commercialization would mean to successfully bring to the market a product and/or service developed during an R&D project. A solid technology transfer process would enable the successful commercialization of new technologies [18]. Improving the technology transfer process and partnerships would improve the commercialization results [7]. Innovations commercialization would be helped by and could move beyond technology transfer [11]. Technology transfer would bridge the gap between R&D and commercialization [28]. If technology transfer is better thought of and understood, chances of successful technology commercialization increase [6]. In summary, scholars agree that technology transfer would enable, improve, or have commercialization efforts as part of the process. Table 17.6 brings a list of studies that mention the relationship.

17.2.8.2 Relationship with Policy-Making

A myriad of studies touch upon policy issues when dealing with technology transfer since the transfer from the public sector to the private is one of the biggest branches of the field. Furthermore, in understanding how crucial the technology transfer process is for the overall technological development of a region/country, public authorities venture to try to boost and promote the process. In 1977, Bar-Zakay published a study that had as primary objective to create policy recommendations to enhance and improve the technology transfer from the military sector to the civilian sector in Israel [16]. In analyzing international technology transfer, Bommer et al. [25] mention government policies as a critical factor to be taken into consideration [25]. In analyzing technology transfer in the solar photovoltaics (PV) industry, Zhang and Gallagher [46] state that government policies would be one of the main drivers [46]. Worrell et al. [5] argue that policies can heavily influence the technology transfer process [5]. Lai and Tsai [42] state "government's policy is always a crucial factor in influencing TT" [42]. Table 17.7 brings a list of studies that mention the relationship.

Table 17.6 Relationship between technology transfer and commercialization

Studies mentioning the relationship	[3, 6, 7, 11–13, 18, 20, 24, 28, 34–37, 44, 48]

Table 17.7 Relationship between technology transfer and policy-making

Studies mentioning the relationship	[2–7, 11–14, 16–18, 20, 24–27, 29, 30, 32, 35, 36, 39, 42, 44–48]

Table 17.8 Relationship between technology transfer and technology assessment

Studies mentioning the relationship	[2, 4, 5, 14, 18, 39, 47]

17.2.8.3 Relationship with Technology Assessment

Technology assessment is another concept/practice that has an intimate relation with technology transfer. It is critical to assess and understand the technology one wants to transfer irrespective of the type of transfer or entities involved. Assessing the technology under different perspectives is always a part of the TT process, whether it is a quantitative process or a qualitative process. Worrell et al. [5] name technology assessment one of the stages of TT, followed by agreement, implementation, evaluation, and adaptation and repetition [5]. Talaei et al. [4] used AHP to assess technologies before recommending policies to transfer energy technologies to developed countries [4]. Similarly, Liu [14] uses technology assessment as part of the transfer process when dealing with aircraft engine technologies [14]. Bar-Zakay [2] argues that technology assessment should be conducted before choosing technologies to be transferred, so as to anticipate the changes and problems a society may face after the new technology is transferred and deployed [2]. As part of their transfer process for the steel industry, Okazaki and Yamaguchi [47] assess the technology and its barriers [47]. Table 17.8 brings a list of studies that mention the relationship.

17.2.8.4 Relationship with Technology Development

There is still, to a degree, a debate in the literature about when technology transfer efforts should start or even if an organization should or not have a formal TT process in place. Some think that TT should start only after the technology development project is done. Others say the TT process should be conducted in parallel. This debate will be further discussed in later sections, but the overlap and interactions between technology development and technology transfer are obvious.

Some authors highlight the interrelationship between public policies promoting technology development and promoting technology transfer [3, 35, 47, 48]. Other authors argue that different TT models are needed for technologies that are at different development stages [18, 34]. Estep [6] links the TT process to the very early stages of technology development, bringing it to the assessment and selection of research proposals [6]. For university TT, Bozeman et al. [3] argue that royalties are greater when more developed technologies are transferred [7]. From an economic standpoint, Siegel et al. [36] stated that when industry partners with academia for TT purposes, the whole sector experiences a greater technological development [36]. Table 17.9 brings a list of studies that mention the relationship,.

Table 17.9 Relationship between technology transfer and technology development

Studies mentioning the relationship	[3, 6, 7, 18, 21, 34–36, 47, 48]

Table 17.10 Relationship between technology transfer and product development

Studies mentioning the relationship	[1, 5, 7, 19, 25, 34, 36, 49]

17.2.8.5 Relationship with Product Development

As already mentioned, there are advantages in filling the gap between technology development and product development by increasing an organization's technology transfer capabilities because the new product development process is likely to go smoother if the technology transfer was adequately done. There are, however, other relationships between the technology transfer process and the actual product development process. Jugend and Silva [49] state that the technology transfer process, among other factors, is vital in having effective new product development projects [49]. As Spann et al. [34] put it, there is a technology transfer component within the product development process [34]. Bommer et al. [25] argue that, for long and costly product development projects, strategic alliances, and transfer skills are highly necessary [25]. In a research on transfer of energy-efficient technologies, Worrell et al. [5] state that better technology transfer skills can lead to better and more environmentally sound products [5]. Nobelius [1] suggests that the transfer to the market should be thought of before the new product development project is over. According to the author, usually, organizations only think about the transfer after the NPD project is done, and that would be a cause of delays [1]. Table 17.10 brings a list of studies that mention the relationship.

17.2.8.6 Relationship with Technology Forecasting

In the literature, the relationship between technology transfer and technology forecasting is not as strong and clear as in other cases, but some authors dwell on the subject. The reasoning is similar to that of the technology assessment concept in that the more information on the technology, the better for planning the transfer. Thus, if a technology forecasting assessment provides an organization with valuable insights on what directions the technology is taking or on what changes are going to be there as a result of the technology application, the better the transfer can be planned and conducted. For the most part, it is said that technology-forecasting assessments are, to some extent, encompassed within the technology transfer efforts [2, 14, 18, 48]. Bar-Zakay [2] is more straightforward, and argues that forecasting skills are necessary for an organization to be successful at transferring technologies [16]. Table 17.11 brings a list of studies that mention the relationship.

Table 17.11 Relationship between technology transfer and technology forecasting

Studies mentioning the relationship	[2, 14, 16, 18, 48]

Table 17.12 Relationship between technology transfer and technology maturity

Studies mentioning the relationship	[4, 12, 18, 38, 39, 48]

17.2.8.7 Relationship with Technology Maturity

As in the case of technology forecasting, scholars do not highlight a strong relationship between technology transfer and technology maturity. However, some interesting insights can be retrieved from the literature. As a general rule, scholars say that technology maturity/readiness would serve as one of the criteria to be considered during the transfer process because technologies that are more ready are easier to transfer [38, 48]. During the transfer assessment of technologies, maturity is an input [4, 12, 18, 39]. In describing the technology platforms implemented in Russia (policy instruments to boost technology development and transfer), Proskuryakova [48] states that technology readiness was one of the criteria considered [48]. Table 17.12 brings a list of studies that mention the relationship.

17.3 Summary

This chapter has brought an overview of the technology transfer literature. Rather than exhausting the whole body of literature on the topic—which goes back more than 40 years—the intention was to give the reader a high-level overview of what has been done so far. Readers can use this chapter as a resource to have a basic understanding of technology transfer and regard it as a starting point for deeper inquiries and investigations. The topics and discussions presented are central to the comprehension and further investigation of technology transfer—the definitions and scope, technology transfer types, mechanisms and methods of analysis, application areas of recent studies and the relationships with other fields.

All of the discussions presented in this chapter can be taken to a deeper level if one chooses to, most importantly concerning the points of contact and relationships between technology transfer and other fields of research. For instance, there are vast amounts of information and research being done in the knowledge management and innovation management fields that can be intimately related to technology transfer concepts and ideas, for example, collaborative research and development, strategic alliances, and open innovation. In that sense, the content presented in this chapter can also be useful to researchers from other fields that are looking for ways to understand how technology transfer relates or affects their research, or to understand how technology transfer concepts can be integrated into their models, propositions, and hypotheses.

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Chapter 18
Technology Transfer Assessment: An Integrated Approach

João Ricardo Lavoie and Tuğrul Daim

18.1 Introduction

This chapter presents a methodological approach to measure an organization's technology transfer capabilities. The integrated approach is a combination of action research in the first phase and a hierarchical decision modeling (HDM) in the second phase, and rather than focusing on assessing a single technology or project/program, focuses on assessing the organization as a whole, i.e., the model brings insights on how ready the organization is in order to successfully transfer technologies from the research stage into an operational stage. The following sections bring a detailed explanation on action research as a research approach and on HDM as a decision-making method, as well as the presentation of the assessment framework with the necessary steps to build the model and to apply it.

18.2 Technology Transfer Assessment Method

This section introduces the two main pillars of the technology transfer assessment method: action research and hierarchical decision modeling.

The proposed method makes use of action research in the preliminary stages (helping to build the initial model) and hierarchical decision modeling (HDM) for the remaining stages. Figure 18.1 summarizes the methodological approach.

As Fig. 18.1 shows, action research and analysis of the body of knowledge (literature review) are jointly used to create inputs for an HDM model. The action

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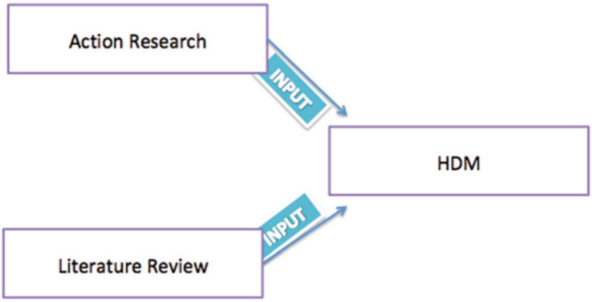

Fig. 18.1 Methodological approach—AR and HDM integration

research component brings the experience and points of view of practitioners who deal with technology transfer on a daily basis, while the literature review components complement it with theoretical insights extracted from decades of relevant research in the field. Both components are then merged into a single hierarchical decision model, which will be then validated and quantified before its application. The following sections explain in further details both action research as an approach and HDM as a decision-making method.

18.2.1 Action Research

Action research is seen as a method for practitioners to get their hands dirty and actively change something in the real world, and it is also seen as an effective method to create knowledge [1]. It is a very diverse and dynamic methodology, and authors argue that there is not a unique definition or manner in conducting action research [1–3]. O'Brien states that action research can be thought of as "learning by doing", and also lists several alternative names the methodology is referred to: participatory research; collaborative inquiry; emancipatory research; action learning; and contextual action research [4]. Tripp defines it as any kind or variation of action inquiry where the researcher aims to improve the practice by ways of acting upon it and later inquiring on the action's results, in a cyclical fashion [5].

Action research brings together and leaps through the traditional divide between research and application since the methodology incurs in researching with practitioners and not researching on practitioners. It is a methodology that lies in the boundary between academia and practice [1]. In the words of Reason and Bradbury, "It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities" [1].

According to Reason and Bradbury [1], the four steps of action research are as follows:

- Step 1: Creating communities of inquiry within communities of practice: Shortens the distance and makes no difference between scientists and practitioners
- Step 2: Building theories in practice: Go to the practical sphere to build theory
- Step 3: Combining interpretation with "rigorous" testing: Tests the theory with practical applications
- Step 4: Changing the status quo: Causes actual change to the practitioner's systems

Similarly, Susman and Evered [6] describe the action research approach in five phases that repeat itself in a cyclical manner:

- Phase 1: Diagnosing: Identifying the problem
- Phase 2: Action Planning: Devising a plan on how to act on the problem
- Phase 3: Action Taking: Executing the plan
- Phase 4: Evaluating: Understanding the results of the actions taken
- Phase 5: Learning: Learning from the experience and starting the cycle over

Action research (AR) is often referred to as a methodological approach, rather than a method, i.e. several methods can fit inside this methodological approach. AR transforms reality, and it is a methodological approach that has a performative perspective as one of its most important components [7]. Strengthening this view of action research as an approach rather than a method itself, Tripp argues that AR cannot be used as a single method in a dissertation, and that it will always require a second method to complement it [5]. Similarly, Dick emphasizes that AR as an approach takes advantage of several different methods and tools to achieve the desired changes [8].

Action research is a way through which researchers influence a system, and this influence (action) also creates important knowledge about the system [6]. It is an approach that creates the conditions for better decision-making about practice, since the process unfolds in a systematic way and inside the practice [9]. To conduct AR, the researcher should, at the same time, actively engage in the action and reflect on the actions taken, generating positive changes to the practical system and generating useful knowledge for the theory [10]. Action research is not only beneficial in practical aspects but also generates knowledge [8]. According to Chandler and Torbert, action research aims not only to understand a system but also to present the future conditions of the system [2]. The approach is focused on resolving real issues and is applied in real conditions and environments rather than in enclosed, controlled, and experimental ones [4]. According to Ferrance, the action research approach brings benefits by focusing on the issue to be solved and by allowing professional development of those involved [3].

Scholars also praise the iterative nature of AR. Tripp says that AR is an approach that makes use of different techniques to provoke changes in reality, and its iterative nature is possibly its most distinguishing feature where the end of a cycle is always the starting point of another and serves as an improvement opportunity [5]. AR operates in iterative cycles of action and reflection on the action, bringing desirable changes that are not easily achieved otherwise [11].

The active participation of the researcher is a very important feature of AR. As Dick summarizes it, even when the word "participatory" is not used, the active participation of the researcher brings several benefits to the approach, such as the commitment to the actions that were agreed upon, the commitment to information sharing, and the commissioning of the people involved in the effort [8]. The participation of practitioners in the process is also very important. In the words of Village et al., "in the AR approach, it is the responsibility of researchers and practitioners together to define the plan, carry out the initiatives, and monitor what is helping or not helping achieve the goal in the organization" [10, p., 1576]. Furthermore, as Dick and Greenwood puts it:

> Action research rejects this pattern of behavior and organization. For action researchers a key concept is a dual commitment to both participants and action. Action research is done with rather than on, the participants – as is often stated. Ideally, the participants become equal partners and co-researchers. The research is done to provide learning and understanding (and theory) that can be used by participants to improve their situation for the benefit of all. For the most action researchers, as far as feasible these are imperatives [11, p. 195].

Notwithstanding its popularity and use in social sciences fields such as psychology, sociology, and anthropology, action research is also indicated as a good way to tackle business and management issues. Although academics may use action research in a way that is excessively theory-oriented for business purposes, there is a balance to be reached so that consultants can make use of the approach to solve management problems [12]. According to Perona et al., action research would be very useful for operations management research, particularly for modeling organizational processes [13]. The action research approach would enable a much deeper and detailed understanding of the organizations being studied when compared to other traditional management research approaches, e.g. surveys and interviews, thus being more advantageous [14]. Specifically with regard to technology management, action research has also been recommended. In his research on knowledge management using participation action research, Otosson argues that had he chosen other more traditional methods of research, the results he achieved would not have been possible [15]. The same author goes on to affirm that the approach has helped especially regarding gathering information and generating insights about new product development, innovation management, and change and project management [15].

As previously explained, action research does not belong to any particular realm or field. On the contrary, the fields of study being explored using the action research approach are numerous. Table 18.1 brings a small sample of what can be found in the literature, regarding the application areas, subjects, and issues being undertaken through action research.

As previously stated, AR is more of a research approach than a research method. It would frame the way the researcher regards the problem, the way the researcher interacts with the people involved in the problem and most importantly, AR would frame the way the researcher tries to solve the problem (research objective). In order to perform AR, the researcher has to actively engage with practitioners, participating in discussions and activities as a member of the team. Further, after this active

Table 18.1 Action research application areas

Area/subject	Reference
Agricultural production	[16, 17]
Aviation	[12]
Community psychology	[18]
Ergonomics	[10]
Health services	[19–22]
Homelessness	[23]
Industrial design	[24]
Manufacturing	[13]
Immigration	[25]
Procurement management	[26]
Religion	[27]
Sexual exploitation	[28]
Supply chain	[29–31]
Teaching	[9]
Technology management	[14, 32]
University—industry partnerships	[33]

participation, changes have to be proposed and implemented, aiming to change the *status quo* and improve the practitioners' systems. If the researcher only describes or facilitates discussions, and if the researcher does not produce any actual changes to the system, he/she would not have used action research. Producing changes is a crucial aspect of action research, and Table 18.2 summarizes the changes sought by researchers in some of the studies available in the literature.

As a research approach, AR can be combined with many different methods for data collection and data analysis. For instance, one could use AR as an approach and use focus groups or interviews as data collection methods and use statistical analysis or grounded theory data analysis methods. In truth, action research must be combined with data collection and data analysis method, because it is not a method in itself, but it is a methodological approach (as explained above). As explained earlier, action research will always require a second method to complement it [5]. This assertion is proven by the fact that the majority of AR studies have one or more "auxiliary methods" to it with the exception made to the conceptual papers that discuss action research as an approach rather than applying it. A myriad of different methods of data collection and data analysis can be effectively and successfully blended into action research, as shown in Table 18.3.

It is clear that AR is a good fit to work with qualitative and quantitative methods that use expert's opinions. Moreover, it has been argued that action research would work well with methods that use ranking and pairwise comparisons, and it should be more utilized coupled with quantitative methods [7].

Table 18.2 Action research producing changes

Reference	Type of change produced in the system
[22]	Change patient education practices in a clinical diabetes setting
[17]	Change the innovation approach for sustainable agriculture in Europe
[23]	Change of homeless women attitude through artwork
[16]	Facilitate agricultural product standardization
[34]	Implement good governance policies for healthcare technology management
[19]	Improve behavioral health services
[32]	Improve customer complaints management through an operations research multimethodology
[33]	Improve knowledge-sharing partnerships between universities and small and medium enterprises
[12]	Improve sustainability in the aviation sector
[14]	Improve technology management by creating a technology management assessment framework
[30]	Improve the process of suppliers evaluation
[20]	Improve the experience of pregnant women in labor and their spouses when meeting and dealing with their caregivers
[31]	Improving decision-making about whether to offshore manufacturing activities
[10]	Improving ergonomics in electronics manufacturing firm processes
[18]	Improving local urban regeneration
[26]	Improving purchasing processes in construction companies
[24]	Including human-centered design perspectives into software development
[27]	Overcome the culture of problem avoidance in non-profit organizations
[21]	Reducing conflicts and enhancing focus in surgery teams
[25]	Resolving identity issues in immigrant Pakistani women
[13]	Shorten manufacturing lead time

Table 18.3 Action research and auxiliary methods

Reference	Auxiliary method
[26, 30, 31]	Analytical hierarchy process (AHP)
[5, 10, 12, 14, 16, 21, 26, 30, 31]	Case study
[7]	Delphi
[19, 30]	Focus groups
[20]	Inductive interpretative qualitative data analysis
[12, 20–22, 27, 32]	Interviews
[7]	Social network analysis (SNA)
[21]	Statistical analysis
[29]	Surveys
[22, 32]	Workshops

18.2.2 Hierarchical Decision Modeling (HDM)

Hierarchical decision modeling (HDM) is an MCDM (multicriteria decision-making) method and was developed in the 1980s by Kocaoglu [35]. The basic idea of HDM is to represent the problem in a hierarchical disposition, so that the decision-makers can visualize which items (criteria and sub-criteria) can affect the objective/mission. According to Munkongsujarit et al., HDM helps the decision-maker by presenting the decision problem as a cascade of problems that are simpler to handle [36]. This model breaks down the various elements of the problem into smaller sub-problems such that the decision problem is represented as a hierarchy [37]. HDM is a tool used in decision-making to rank and evaluate the available alternatives and to determine the best among them [36]. It is a tool that helps decision-makers quantify and incorporate quantitative and qualitative judgments into a complex problem [38].

HDM has been used in a variety of cases and for several purposes, especially in technology management, trying to evaluate and tell which technology alternative is the best option in a particular setting, given the criteria established to evaluate the alternatives. According to Munkongsujarit et al., hierarchical decision models assist the decision-makers by providing a systematic way to evaluate all available alternative solutions to the problem according to the relative importance of the criteria and finally in identifying the best possible solution [36].

The basic structure of HDM can vary depending on each application needs. The most traditional structure is the MOGSA, a five-level structure containing Mission, Objectives, Goals, Strategies, and Actions. However, simpler structures can be used, such as a three-level model containing Mission, Criteria, and Alternatives or a four-level model containing Mission, Criteria, Sub-Criteria, and Alternatives. According to Sheikh et al., with HDM, multiple perspectives can be prioritized and their associated criteria can be ranked [39] so as to understand which criteria and/or perspectives are more important and to what degree.

In order to apply HDM, it is necessary to select experts (in the specific studied field) who will help create the model and evaluate the relationships between objective, criteria, sub-criteria, and alternatives. The experts make pairwise comparisons among the items in the model (criteria, sub-criteria, and alternatives) to determine its weights and relationships using the constant-sum method (dividing a total of 100 points between the items being evaluated). The results of the comparisons are then extracted into matrixes, which in turn will have their values normalized and processed in order to rank the alternatives. In the end, it is possible to determine which alternative is the best, considering the criteria and evaluations made by the experts involved. As Turan et al. state, in the HDM model, pairwise comparisons are made to express the importance of one element of the decision problem with respect to another (criteria and alternatives) [40].

As stated earlier, HDM has been applied in several different settings and fields, proving that it is, indeed, an effective method. The fields and areas that were explored using HDM are (but not limited to) computer selection [37]; agriculture [41]; university housing [36]; selection of graduate school [40]; transportation options [42]; solar photovoltaic technologies [39]; health technology assessment [43]; semiconductors industry [38]; energy [44]; and technology transfer [45]; among others.

Engineering and research managers are frequently faced with multilevel decisions under conflicting objectives and criteria. They develop technical strategies to fulfill multiple goals; allocate resources to implement multiple strategies; and evaluate their projects and programs in terms of time, cost, and performance characteristics [35]. As the world has become more complex, decision problems have followed suit and must contend with increasingly complex relationships and interactions among the decision elements. To assist decision-makers and analysts, different methods have been developed to decompose problems into hierarchical levels and formulate hierarchical decision models (HDM) [46]. As Taha et al. state, the decision process is as important as the decision itself. Thus, choosing the right method to aid in the decision process can be the difference between success and failure [37]. Still, according to the same authors, the best decision model to use when subjective judgment is needed to evaluate and select a solution with many criteria is the hierarchical decision model (HDM) [37].

The concept of desirability functions is used to calculate the technology transfer score. For each of the factors in the model, levels (or metrics) are set and experts are prompted to assign a desirability value for each of those levels between 0 and 100 (with 0 representing the least desirable situation and 100 representing the most desirable situation). The desirability values are used to plot the desirability curves, and the curves' distribution will change depending on the very nature of each factor. The great advantage of using desirability functions is the flexibility it provides to the model. After apprehending experts' judgments on each factor through the desirability values, one can replicate the model and apply it again and again using different alternatives, without having to go back and consult with the experts, provided the weights of perspectives and factors remain unchanged. Conversely, if one does not use desirability functions, one would have to go back to the experts and start the quantification process anew with every change in the alternatives.

According to the HDM methodology developed by Kocaoglu [35], pairwise comparisons are made between each item in every layer of the model. After conducting the pairwise comparisons, normalized matrices are generated with the expert judgments. The importance of every component of a given layer relative to the layer right above it is extracted by averaging the rows of the normalized matrices. The importance of every model component relative to the first layer (or the global importance) is calculated by multiplying its local importance (relative only to the layer above it) by the importance of its "parents" relative to the first layer. By bringing this rationale to the model, and using three layers, the calculation of the factors' importance relative to the mission (organizational TT score) will be given by the following equation:

$$S_{n,jn}^{\mathrm{TT}} = \sum_{n=1}^{N} \sum_{jn=1}^{Jn} \left(P_n^{\mathrm{TT}}\right)\left(F_{n,jn}^{P}\right)$$

where $S_{n,jn}^{\mathrm{TT}}$ = relative value of the j_nth factor under the nth perspective with respect to the TT score; P_n^{TT} = relative priority of the nth perspective with respect to the TT score, $n = 1, 2, 3 \ldots N$; and $F_{n,jn}^{P}$ = relative contribution of the j_nth factor under the nth perspective, $j_n = 1, 2, 3 \ldots N$.

After having the importance of each factor relative to the mission, the determination of the organizational TT score will be given by multiplying the global importance of each factor by its desirability value and making the total summation as shown in the following equation:

$$\text{Org TT Score} = \sum_{n=1}^{N} \sum_{jn=1}^{Jn} \left(S_{n,jn}^{\mathrm{TT}}\right)\left(D_{n,jn}\right)$$

where $S_{n,jn}^{\mathrm{TT}}$ = relative value of the j_nth factor under the nth perspective with respect to the TT score; $D_{n,\,jn}$= desirability value of the performance measure corresponding to the j_nth factor under the nth perspective.

During the quantification phase, the levels of individual logical inconsistency and group disagreements are also calculated. The inconsistency level measures how logical each expert is when performing the pairwise comparisons. For instance, given three factors A, B, and C, if A is better than B and B is better than C, A must be better than C if one is to be logically consistent. The disagreement level measures how much disagreement exists between the various experts in their judgments. In the words of Phan:

> For n elements, the constant sum calculation results in a vector of relative values r1, r2, . . . , rn for each of the n! orientations of the elements. For example, if three elements are evaluated, n is 3, and n! is 6. The 6 orientations would be ABC, ACB, BAC, BCA, CAB, and CBA. If an expert is consistent in providing pairwise comparisons, the relative values are consistent for each orientation. However, if an expert is inconsistent in providing pairwise comparisons, the relative values are inconsistent for each orientation. The inconsistency in this methodology is measured by the variance among the relative values of the elements calculated in the n! orientations. [45, 47]

The formulas to calculate the inconsistency level are as follows, adapted from [35, 47, 48]:

Let:

r_{ij} = relative value of the ith element in the j^{th} orientation for an expert.
$\bar{r}_i$= mean relative value of the i^{th} element for that expert.

$$\frac{1}{n!}\sum_{j=1}^{n!} r_{ij}$$

Inconsistency in the relative value of the *i*th element is

$$\sqrt{\frac{1}{n!}\sum_{j=1}^{n!}\left(\bar{r}_i - r_{ij}\right)^2} \text{ for } I = 1{,}2{,}3\ldots n$$

Variance of the expert in providing relative values for the *n* elements is

$$\text{Inconsistency} = \frac{1}{n}\sum_{i=1}^{n}\sqrt{\frac{1}{n!}\sum_{j=1}^{n!}\left(\bar{r}_i - r_{ij}\right)^2}$$

The disagreement level formula is as follows, adapted from [47, 48]:

$$d = \sqrt{\frac{1}{m}\sum_{j=1}^{m}\frac{1}{n}\sum_{i=1}^{n}\left(R_i - r_{ij}\right)^2}$$

where R_i = group relative value of the *i*th element; m = number of experts; n = number of decision variables; r_{ij} = mean relative value of the *i*th element for the *j*th expert.

18.3 Proposed Framework

Figure 18.2 is a chart illustrating the approach used.

18.3.1 First Step: AR and Literature Review

As the first step, a literature review and an action research project are conducted. As previously explained, the literature review contributes with the concepts and factors that have been investigated and analyzed through decades of academic research in the field of technology transfer. The action research project, conversely, contributes with the points of view, expertise, and daily challenges faced by technology managers in a practical setting. It is imperative for the researcher to go through all four stages of the action research project in order for him/her to be able to better integrate the concepts and factors that arise from the practice with those found in the body of knowledge.

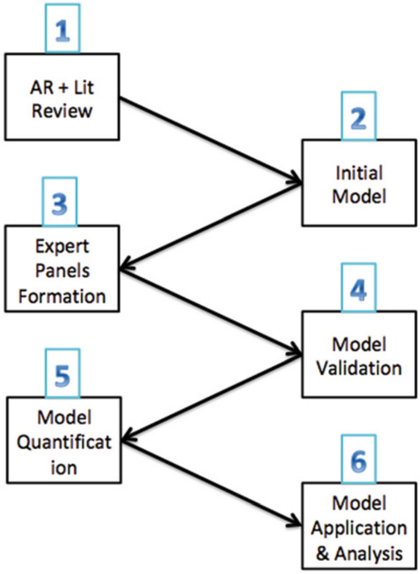

Fig. 18.2 Research approach

18.3.2 *Second Step: Initial Model*

The second step merges the concepts and factors identified in the previous step, and these are used by the researcher to build an initial HDM model, following the methodology described in previous sections.

18.3.3 *Third Step: Expert Panel Formation*

According to the Cambridge dictionary, an expert is “a person having a high level of knowledge or skill in a particular subject” [49]. Expert panels are a group of experts who are summoned together to gather and discuss a subject or provide a service, such as feedback or recommendations [50]. In the third step, experts are identified to provide input to the model, by validating the initial model and then quantifying it.

The most important challenges in working with expert opinions are the potential biases and their overconfidence in judging subjects and situations they know well [51]. In the words of Morgan, “because experts are human, there is simply no way to eliminate cognitive bias and overconfidence” [52, p., 7183]. Identifying and recruiting the best experts to the situation, and at the same time making sure the results of the panel are reliable, is also a significant challenge [48, 53].

Balancing the expert panel is also a concern, and researchers need to make sure each panel represents a robust and significant sample of the existent knowledge on the field [48].

The size of the panels is a major concern as well [48]. Commenting on the Delphi method, Phan states that the most recommended size of an expert panel would be from 10 to 15 experts [47]. Nonetheless, successful studies have been conducted utilizing sub-groups of experts as small as five members [54] or three members [53]. Since dealing with a large number of experts augments the process complexity exponentially, it has been argued that the maximum amount of experts per panel should be 12 [55]. Leveraging the work done in past dissertations [45, 48, 53, 54, 56, 57], it is safe to say that expert panels composed of 6–12 experts each are reliable and at the same time manageable.

Experts should be selected taking into account several aspects, such as how much of an expert the person is by noting what were the contributions and the significance of their contributions to the field of study; minimizing the bias as much as possible (i.e., checking if the selected experts have any special reason or personal interest that would enhance the bias potential); and noting how available or willing the experts are (i.e., not only the person should be an expert, but also he/she should be willing to fully participate in the study, as to spend enough time and attention taking care of their tasks as an expert [48, 54, 56]).

Due to the challenges aforementioned, the process of selecting the expert is not a trivial task. The most proper methods to choose experts, according to Tran, are the use of personal connections, such as if the researcher has easy access to knowledgeable people in the field; snowball sampling where the researcher starts with a small group of experts, who in turn recommend more experts and so on; social network analysis where the researcher draws on a network based on collaborations, coauthorship, or citations in order to discover the most relevant and influential actors in the field of study [53].

18.3.4 Fourth Step: Model Validation

The model validation step is illustrated by Fig. 18.3.

Survey instruments are created and sent to the experts along with documents explaining the objectives of the research and explaining the model. All details and steps of the model building and also the objectives of the model should be clearly and thoroughly explained, so that biases and misunderstandings are minimized.

Fig. 18.3 Model validation framework

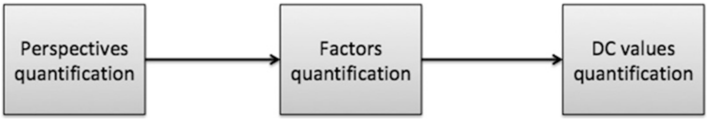

Fig. 18.4 Model quantification framework

This process is repeated for validating the model's perspectives, factors, and desirability curve metrics.

18.3.5 Fifth Step: Model Quantification

The model quantification step is illustrated by Fig. 18.4.

Research instruments are created and sent to the experts, along with documents explaining the objectives of the research and explaining the model. Although there are software available to collect and analyze the experts' input, the researcher could also opt to collect the data via online survey systems and then process the data afterward.

18.3.6 Sixth Step: Model Application and Analysis

As the last step, the model is applied in the organization for which the researcher wishes to assess the technology transfer capabilities. Internal subject matter experts and managers should be contacted in order to determine at which point of every desirability curve the organization in question is situated. After the model is applied, sensitivity analysis should be performed in order to check and understand the impact on the total TT score due to changes in the priorities (importance) of model perspectives. Following is an explanation of possible inconsistency, disagreement, and sensitivity analyses.

18.3.6.1 Inconsistency Analysis

The inconsistency analysis is one of the key data analysis items in applying the HDM methodology [53]. According to Estep, "generally, inconsistency can be defined as disagreement *within* an individual's evaluation" [45, p. 75]. In the words of Abotah, "inconsistency is a measure that explains how reliable and homogeneous in his or her answers each expert was through the whole questionnaire" [48, p. 64]. In other words, the inconsistency of an expert can be thought of as the logical incoherence of his/her judgments. For instance, given three factors A, B and C, if A is better than B and B is better than C, A must be better than C if one is to be logically consistent (ordinal consistency). Moreover, if A is two times better than B and B is three times better than C, then A must be six times better than C, if one is to be logically consistent (cardinal consistency). Chan argues that inconsistencies in experts' judgments are common in AHP-based studies [54]. Following the same reasoning, Gibson states that one should expect inconsistency to occur when experts face multiple decisions and have to judge items [57].

In more technical terms, in the words of Phan from his PhD dissertation in 2013:

> For n elements, the constant sum calculation results in a vector of relative values r1, r2, . . ., rn for each of the n! orientations of the elements. For example, if three elements are evaluated, n is 3, and n! is 6. The 6 orientations would be ABC, ACB, BAC, BCA, CAB, and CBA. If an expert is consistent in providing pairwise comparisons, the relative values are consistent for each orientation. However, if an expert is inconsistent in providing pairwise comparisons, the relative values are inconsistent for each orientation. The inconsistency in this methodology is measured by the variance among the relative values of the elements calculated in the n! orientations. [45, p. 47]

The formulas to calculate the inconsistency level are the following, adapted from [35, 47, 48]:

Let

r_{ij} = relative value of the ith element in the j^{th} orientation for an expert;
$\bar{r}_i$= mean relative value of the i^{th} element for that expert;

$$\frac{1}{n!}\sum_{j=1}^{n!} r_{ij}$$

Inconsistency in the relative value of the i^{th} element is

$$\sqrt{\frac{1}{n!}\sum_{j=1}^{n!}\left(\bar{r}_i - r_{ij}\right)^2} \text{ for } I = 1{,}2{,}3 \dots n$$

Variance of the expert in providing relative values for the n elements is

$$\text{Inconsistency} = \frac{1}{n}\sum_{i=1}^{n}\sqrt{\frac{1}{n!}\sum_{j=1}^{n!}\left(\bar{r}_i - r_{ij}\right)^2}$$

As noted by Kocaoglu [35] and as per the precedent established by other studies [45, 48, 53, 54, 57], the inconsistency level should not be higher than 10%, in order to be taken as acceptable. Should the inconsistency level exceed the 10% mark, a more careful consideration should be made (e.g., the most inconsistent experts should be asked to repeat the judgments, and in extreme cases the most inconsistent judgments could be deleted from the analysis) [57]. Additionally, in case of large inconsistencies, another method of calculating the inconsistency could be used to further analyze the matter, such as the root-sum of variances created by Abbas [58]. His method utilizes the root-sum of the variances (RSV) and it takes into account the number of pairwise comparisons experts are making. The following formulas depict the calculations used and are adapted from [58].

$$\mathrm{RSV} = \sqrt{\sum_{i=1}^{n} \sigma_i^2}$$

where HDM inconsistency = root of the sum of variances (RSV) and $\sigma_{\mathrm{i}}{}^2$ = variance of the mean of the i^{th} decision element.

$$\sigma_i = \sqrt{\frac{1}{n!} \sum_{j=1}^{n!} \left(x_{ij} - \bar{x}_{ij}\right)^2}$$

where x_{ij} = normalized relative value of the variable i for the j^{th} orientation in n factorial orientations and $\bar{x}_{ij}$ = mean of the normalized relative value of the variable i for the j^{th} orientation.

$$\bar{x}_{ij} = \frac{1}{n!} \sum_{j=1}^{n!} x_{ij}$$

where $\bar{x}_{ij}$ = mean of the normalized relative value of the variable i for the j^{th} orientation and x_{ij} = normalized relative value of the variable i for the j^{th} orientation in n factorial orientations.

18.3.6.2 Disagreement Analysis

The disagreement analysis is also noted as one of the key data analysis items in applying the HDM methodology [53]. In the words of Tran, "the agreement among the experts' judgment is represented by a disagreement value of the expert group in a pairwise comparison procedure" [53, 65, p.]. Quoting from Abotah's dissertation, "the disagreement of experts can be understood as the deviation of their judgments from each other" [48, p. 59]. To measure and treat the disagreement levels would be especially important in order to guarantee the significance of the results of experts' judgments [53]. It could be problematic if researchers did not check the agreement level between the raters before making any data analysis [59].

Although disagreement would be something natural among experts, it should be treated. In case the disagreement level is greater than what is acceptable, another round of judgments could be conducted with the aim to reach a consensus or quasi-consensus situation (following the Delphi methodology). However, in cases where the vast majority of experts agree but there is one or a few outliers bringing the disagreement level up, a follow-up with the outliers should be conducted in order to check if they have correctly interpreted the components and concepts involved in the study [45], and the removal of those outliers from the pool of experts could also be contemplated as a viable option in extreme cases.

A common method of measuring the disagreement between experts is to use the PCM group disagreement index, according to the following formula, which is adapted from [47, 48, 56].

$$d = \sqrt{\frac{1}{m}\sum_{j=1}^{m}\frac{1}{n}\sum_{i=1}^{n}\left(R_i - r_{ij}\right)^2}$$

where R_i = group relative value of the ith element; m = number of experts; n = number of decision variables; r_{ij} = mean relative value of the ith element for the jth expert.

In order to use this method, precedent has it that an acceptable disagreement level would be 10% or less [45, 48, 56, 57]. Hierarchical agglomerative clustering (HAC) has also been used in previous dissertations to complement the disagreement measurement and interpretation [56, 57].

Two other very common methods of measuring the disagreement among experts are the intraclass correlation coefficient (ICC) and the F-test. Several authors have used ICC and F-test as the measurements of disagreement among experts [47, 53, 54].

The ICC would be at the same time a measure of intrarater reliability and interrater reliability, and it is extensively used across different disciplines [59, 60]. A complete agreement between experts would result in the ICC yielding the value 1.00, while a complete disagreement between experts would result in the ICC yielding the value 0. It has been argued that an ICC of 0.7 or higher would indicate an acceptable level of agreement [61]. However, there are authors reasoning that the minimum acceptable ICC would vary on a case-by-case basis, heavily depending on the research questions, objectives, and data used [59]. There are several different ways of applying ICC, and there are three different models with different options of forms and types. The researcher should be aware of his/her needs in order to choose the most proper ICC model and its features [59].

The ICC is estimated according to the following formula, adapted from [60]:

$$\mathrm{ICC} = \frac{\mathrm{MS}_R - \mathrm{MS}_E}{\mathrm{MS}_R + (K-1)\mathrm{MS}_E + \frac{K}{N}(\mathrm{MS}_C - \mathrm{MS}_E)}$$

where MS_R = mean square for rows (i.e., targets); MS_C= mean square for columns (i.e., judges); MS_E= mean square error of all obtained from a two-way ANOVA; K = number of observations (e.g., ratings or judges) for each of the N targets; and N = number of targets.

The F-test is a statistical test used to compare the ratio of two variances. Some of the assumptions of the test are that the population variances are equal (therefore, the null hypothesis will be that the variances are equal), the population has approximately a normal distribution, and the samples must be independent events [62]. The work done by Shrout and Fleiss in 1979 used ICC as a basis and F-test to check the disagreement levels between raters [63]. It tests a null hypothesis $H_0 : \mathrm{ICC} = 0$, meaning that there is no correlation between the values and thus there is an absolute disagreement between the experts. If the null hypothesis is rejected, the $H_1 : not\ H_0$ is confirmed, meaning there is not a statistically significant disagreement between experts. The F ratio is calculated by the following formula:

$$F = \frac{\mathrm{MS}_R}{\mathrm{MS}_E}$$

The resulting ratio is then compared with the F-critical value with the degrees of freedom $df_1 = df_R$ and $df_2 = df_E$ at a specific level of confidence (usually 95% and above). If the calculated ratio is greater than the F-critical value, the null hypothesis can be rejected (at that specific level of confidence) and no significant disagreement between experts would be present.

18.3.6.3 Sensitivity Analysis

The impacts of potential changes in the values on the top level of a model, or any other level, for that matter, are done by ways of conducting a sensitivity analysis. This test is important because the preset priorities (or weights) of a model's components might change over time [56, 57], and that is especially true in the realm of technology where changes occur extremely rapidly and constantly. Also, changes in the expert panels might bring new priorities (weights), and given the fact that these changes might occur, a sensitivity analysis would be appropriate [45]. The sensitivity analysis shows how strong the decisions and conclusions coming from the model are [48]. It is performed to test and assure the robustness of both the model and the results [56]. The test would also be helpful in enhancing the comprehension of how each level of the model and its components relate to each other [54].

In cases where the model's output is the ranking of different alternatives, the sensitivity analysis is especially useful to tell if and how much that original ranking would change due to changes in the priorities of the model's components [47, 56]. For instance, the final ranking of the alternatives might be altered if the criteria relevance is altered, and the sensitivity analysis would measure how strong or disruptive these changes would be.

Scenarios can be used to test how much the ranking would be altered in a particular setting (e.g., if one of the top-level priorities is overwhelmingly more important than the rest), as it was done in previous studies [45, 48]. Notwithstanding the usefulness of testing the sensitivity of a model through different scenarios, in order to calculate how much perturbation in its priorities a model would endure before yielding different results, a more complex method has to be applied. Such a method was created by Chen and Kocaoglu, and it calculates the tolerance of a model to changes (i.e., the allowed range of values within which a contribution can change without altering the final ranking produced by the model) [46]. The method was detailed in Chen's dissertation [64], and has been extensively used since then [45, 47, 53, 54, 56].

The method states that the original output of the model (original ranking) will not be changed if

$$\lambda \geq P_i^C . \lambda^C$$

for the perturbation P_{l*}^C where

$$-C_{l*}^C \leq P_{l*}^C \leq 1 - C_{l*}^C$$

and

$$\lambda = C_r^A - C_{r+n}^A$$

and

$$\lambda^C = C_{r+n,\,l*}^{A-C} - C_{rl*}^A - \sum_{l=1,\,l\neq l*}^{L} C_{r+n,\,l*}^{A-C} . \frac{C_l^C}{\sum\limits_{l=1,\,l\neq l*}^{L} C_l^O} + \sum_{l=1,\,l\neq l*}^{L} \frac{C_{rl}^{A-O}}{\sum\limits_{l=1,\,l\neq l*}^{L} C_l^O}$$

The allowance range of perturbations C_i^C to maintain the original ranking is given by

$$\left[\delta_{i-}^C, \delta C_{i+}^O\right]$$

and the sensitivity coefficient is given by

$$1/ \mid \delta_{i+}^C, \delta_{i-}^C \mid$$

18.4 Summary

This chapter has presented a methodological approach to build a hierarchical decision model to be used to assess an organization's technology transfer capabilities. The approach consists of utilizing both an action research component and a literature review components in order to provide input for the building of the model. The application of the model, also explained in this chapter, could lead to a higher understanding and awareness of the technology transfer capabilities of an organization, and also can be used as a starting point to promote beneficial changes in the organization's processes, ultimately leading to better results and more benefits from research and development through a more robust technology transfer process.

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Chapter 19
Evaluating Technology Transfer: Case of a Power Utility

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19.1 Introduction

This chapter presents the application of an action research and hierarchical decision modeling-based methodology to assess an organization's technology transfer capabilities. The model was applied in the Northwest region in the United States. More specifically, the Bonneville Power Administration (BPA) was the organization assessed in this study. The action research, aiming at enhancing the agency's technology transfer process, lasted for approximately 2 years before the model was built.

BPA is a federal government agency, part of the Department of Energy (DoE), and it is responsible for marketing wholesale electricity in the Northwest region in the United States. As a federal power marketer, BPA manages and markets power from dozens of hydroelectric power plants as well as nuclear power plants in the region, and manages, maintains, and operates almost 75% of all high-voltage electricity transmission in the regions it serves—Washington, Oregon, Idaho, Montana, and smaller pieces of Northern California, Nevada, Utah, and Wyoming. In spite of being part of the DoE, BPA is 100% self-funded and also heavily invests in innovation and technology development. Most of the research and development efforts done by the agency are managed by the Technology Innovation Office, which was established in 2005, creating a disciplined and structured program for funding and deploying research, development, and demonstration projects, aiming to leverage the new technological possibilities to modernize the power grid and to offer better, more reliable, and more affordable services for its customers. Technology transfer is seen as a key component of the Technology Innovation Office's R&D

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management structure, especially because the majority of the funded projects are developed and led by external parties (national labs, universities, and companies) involving hundreds of different people and organizations. The project outcomes, in turn, will have to be transferred into BPA's operations as smoothly as possible; hence, having a solid and robust technology transfer process becomes of the utmost importance. The action research project described in this chapter—which included the authors, as well as the application of the HDM model—is part of the efforts conducted by BPA in order to create solidity and robustness in its technology transfer capabilities.

The remaining sections are organized as follows: the characteristics of the action research project that led to the application of the model, conducted at BPA, will be explained in the next section. Next, the model-building process is shown, as well as the explanation of each component in the model. Next, the implementation of the developed model is depicted—using Bonneville Power Administration as a case—and the results are shown and analyzed. As part of the analysis, the generalization of the model will be discussed, and the applicability of the model for other organizations and other sectors. Finally, conclusions are drawn, the model's limitations are explained, and future opportunities for research are identified.

19.2 Action Research Project

As explained by Reason and Bradbury [1], the four building blocks of an action research project are the following:

- To create communities of inquiry within communities of practice, shortening the distance, and making no difference between scientists and practitioners.
- To build theories in practice by going to the practical sphere to build the theory.
- To combine interpretation with testing by testing the theory with practical applications.
- To change the *status quo* by causing actual changes to the practitioner's systems.

If a given project follows these steps and has these components, it can be confidently characterized as an action research project. BPA's technology transfer project has made the agency's TT framework to evolve over time, and the process through which the framework has evolved has gone through all four steps of an action research project, as explained in the next paragraphs.

The research team was actively involved in the project, not only as observers but as members of the team, engaging in conversations, participating in discussions and meetings, and bringing ideas, concepts, and insights to the table. This active participation remains until today, perfectly characterizing the first step of AR. Moreover, a fair share of the project's first step was devoted to the researchers, so that they could understand and familiarize themselves with the practitioners' systems, processes, and environments. Clearly, there was no difference between researchers and practitioners.

Also, during the first months of the project, the researchers were diving into the literature looking for and analyzing technology transfer frameworks. The objective of this task was for the researchers to present the theoretical models and frameworks and discuss them with the team, and to compare these theoretical frameworks with the current practice the agency had, proposing changes and enhancements. Several rounds of discussion were conducted The researchers would acquire information and share with the entire team; the team (researchers included) would discuss the ideas, contrast them with the current system and propose changes; and the researchers would then go back to the literature and restart the cycle. This entirely satisfies the second step, where researchers have to go back and forth between theory and practice, engaging practitioners in discussions, and proposing changes to their systems. The development of project evaluation instruments (forms) serves as an example. These forms were developed based on a comprehensive pool of criteria and perspectives present in the literature and brought to the team by the researchers (several iterative cycles were undertaken). Both the application timing and criteria to be used in each form were extensively discussed with active participation from both practitioners and researchers.

Throughout the project, whenever an idea was being developed, several iterative cycles of discussion and revision were taken. After the result was considered acceptable, the team would pilot that result with the project managers and other stakeholders. This fits perfectly into the third AR step definition. In action research projects, researchers are not only prompted to suggest changes to practitioners' systems, but also to test those changes.

The fourth and last step of an action research project requires researchers to go beyond everything they did in the first three steps. After actively participating in discussions and understanding the practitioners' systems, having gone back and forth between theory and practice suggesting changes, and having tested those changes, the researchers have to implement those changes and analyze the results, going back to the first step afterward, if necessary.

Additionally, it is possible to zoom out a bit and analyze the project unfolding from a higher level. If one is to do that, one will inevitably reach the same conclusion—that this has been an action research project. The first phase of the project was one of an exploratory nature when the researchers were discussing the practitioners' systems and understanding it in a very active fashion (thus creating a community of inquiry within a community of practice, shortening the distance between researchers and practitioners). The next step was to analyze both the literature and BPA's processes, suggesting changes and enhancements to the process, and a journal article about this experience was published [2] (building theory in practice by going to the practical sphere to build theory). Next came the testing and implementation of the proposed changes and enhancements (testing the theory with practical applications and causing actual changes to the practitioners' systems). Lastly, the project team is currently aiming to analyze the results of the changes made. By doing so, the team will be able to understand how the current (changed) system looks like and propose new changes to enhance it further, which could prompt the start-the-action research process anew.

19.3 The Model

Before presenting the model, its components are listed by source. Table 19.1 brings factors coming from the literature review and Table 19.2 brings factors coming from the action research.

The initial research model is depicted in Fig. 19.1.

A brief description of the model components is provided in Tables 19.3 and 19.4.

19.3.1 Metrics for Desirability Curves

Following the steps described by Estep (2017) [1], experts are used to quantify the desirability curves. For each factor in the model and according to how desirable the category is, experts are presented with the units of measurement and its categories, assigning between 0 and 100 points to each category. The curves are drawn after the average of the experts' assessments is calculated. The units of measurements and categories for each factor in the model are briefly presented below.

Table 19.1 HDM factors from the literature

Factors in the model coming from the literature
TT team and training
TT ecosystem management
Senior management involvement
Communication and knowledge management
Funding
Absorptive capacity
Long-range planning
Technology valuation
Proposal assessment
Benefit management
TT mechanisms management
Business plan and use case
Continuity of TT process

Table 19.2 HDM factors from action research

Factors in the model coming from the action research
Stakeholders management
TRL assessment
Data management
Risk management
Outcomes and decisions
Value, impact, and applicability management
TT planning, control, and flexibility
Parallel processes integration

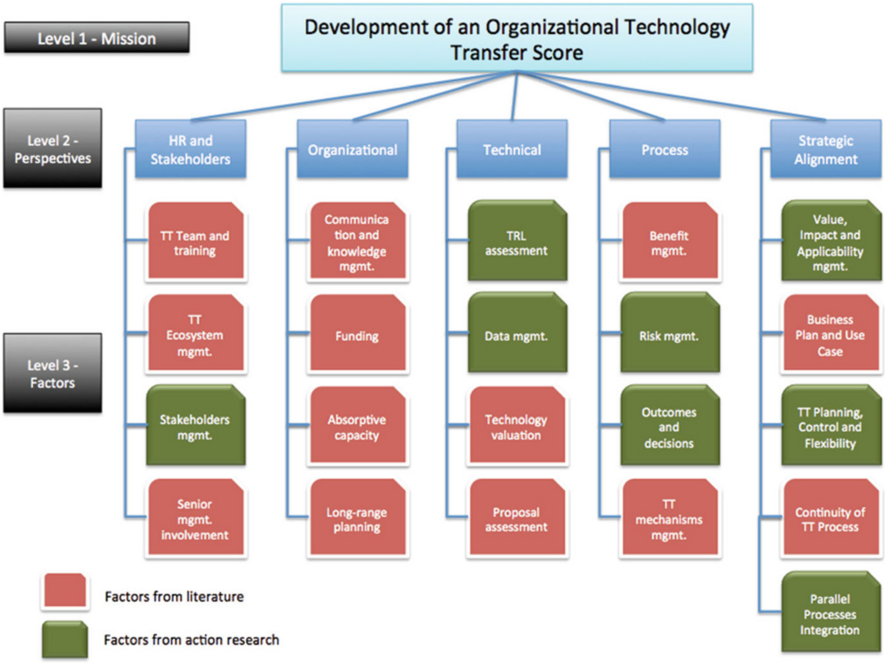

Fig. 19.1 Initial model

Table 19.3 Description of model perspectives

Perspective	Description
Human resources and stakeholders	Factors related to the team, training, ecosystem, senior management, and other players involved
Organizational	Factors related to organizational characteristics that should be in place for a better TT process
Technical	Factors related to technical assessments and technology quantifications
Process	Factors related to the TT process features and characteristics
Strategic alignment	Factors related to the alignment between R&D and business strategy, and the integration of TT with other managerial processes

19.3.1.1 Human Resources and Stakeholders Perspective

TT Team and Training

This factor is measured by aspects related to the existence or not of a dedicated TT team; the background of people in the team; whether or not the team is multidisciplinary; and the type and frequency of training. The categories are as follows:

Table 19.4 Description of model factors

Perspective	Factor	Description	Source
Human resources and stakeholders	TT team and training	Is there a dedicated TT team? Background of people in the team; is the team multidisciplinary? Type and frequency of training	[3–6]
	TT ecosystem mgmt	Relationship, cooperation, and partnership with the TT ecosystem members, e.g., TTOs, science parks, research centers, incubators, POC centers, etc.	[4, 5, 7–9]
	Stakeholders mgmt	Interactions and cooperation with internal and external stakeholders to increase participation and create awareness (within the boundaries of the TT process)	Action research
	Senior mgmt involvement	Awareness, approval, support, and active participation of senior managers in the TT process	[4]
Organizational	Communication and knowledge mgmt.	Relevance and frequency of interactions between stakeholders, transfer and sharing of knowledge between different departments (outside the boundaries of the TT process)	[10]
	Funding	Ease of access and level of funding for transfer activities	[3, 4]
	Absorptive capacity	Capabilities related to identifying valuable information, assessing, and using it	[7]
	Long-range planning	Corporate strategy and long-term technology planning	[6, 11]
Technical	TRL assessment	Determination of technology readiness levels and related metrics, e.g., IRL; SRL; RD3	Action research
	Data mgmt	Standardization, acquisition, storage, recovery, and analysis of the project data	Action research
	Technology valuation	Technology assessment studies at several different points throughout the technology development cycle	[12]
	Proposal assessment	Qualitative and quantitative assessments of research proposals	[4]
Process	Benefit mgmt	Identification, understanding, description, classification, and monitoring of benefits	[4]
	Risk mgmt	Identification, understanding, description, classification, and monitoring of risks and opportunities	Action research
	Outcomes and decisions	Discussions, reports, and decisions made out of the TT process	Action research
	TT mechanisms mgmt	Identification, understanding, description, classification, and monitoring of potential TT mechanisms	[7, 13, 14]

(continued)

Table 19.4 (continued)

Perspective	Factor	Description	Source
Strategic alignment	Value, impact, and applicability mgmt.	Economic value and strategic fit; level of impact of daily operations and beyond; ease of applicability and extra requirements, such as adjustments, adaptations, and special training	Action research
	Business plan and use case	Planning of the technology application, based on benefits, value, impact, and applicability	[3, 4]
	TT planning, control, and flexibility	Continuous improvement of the TT process; meetings, planning, reviews, setting objectives and priorities, and adjusting those based on market and strategy changes	Action research
	Continuity of TT process	Length and comprehensiveness of TT process; ideal to start before project selection and go through postdevelopment phases	[10, 13, 15]
	Parallel processes integration	Integration, feedback, and information exchange from and to other managerial processes, e.g., project, portfolio, and program management and roadmapping	Action research

- No dedicated TT team and no training.
- Dedicated TT team: not multidisciplinary; no training.
- Dedicated TT team; slightly multidisciplinary (with representatives from more than one department); either no training or informal training.
- Dedicated TT team; multidisciplinary (with representatives from all relevant departments); formal training.
- Dedicated TT team; multidisciplinary (with representatives from all relevant departments); formal periodic training (quarterly-based or more often).

TT Ecosystem Management

This factor is measured by aspects related to the existence or not of TT ecosystems and the strength of the relationship, cooperation, and partnership with the TT ecosystem members, such as TTOs, science parks, research centers, incubators, POC centers, etc. The categories are as follows:

- No interaction with the TT ecosystem entities whatsoever.
- Sparse interaction with the TT ecosystem (less than monthly); no cooperation.
- Frequent interaction (at least monthly); no cooperation.
- Frequent interaction (at least monthly); formal agreement with some TT ecosystem entities (up to three).
- Frequent interaction (at least monthly) and formal agreement with multiple TT ecosystem entities (more than three).

Stakeholders Management

This factor is measured by aspects related to the interactions and cooperation with internal and external stakeholders to increase participation and create awareness (within the boundaries of the TT process). The categories are as follows:

- TT process is limited to the TT team alone; no one else participates.
- TT team has sparse contact (less than monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders, but with solicitation).
- TT team has frequent contact (at least monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders, but with solicitation).
- TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders and without solicitation).
- TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes both ways (from and to stakeholders).

Senior Management Involvement

This factor is measured by aspects related to the awareness, approval, support, and active participation of senior managers in the TT process. Leveraging the work done by Estep (2017) [1], the categories are as follows:

- There is no senior management interest in the process.
- TT process is supported by middle management, but their engagement is not consistent.
- Middle management is actively engaged in the TT process, but senior management still does not openly support it.
- Senior management is aware of the TT process, but their engagement is not consistent.
- There is evidence of consistent engagement and support for the TT process at all levels of the organization.

19.3.1.2 Organizational Perspective

Communication and Knowledge Management

This factor is measured by aspects related to the relevance and frequency of interactions between stakeholders, and the transfer and sharing of knowledge between different departments (outside the boundaries of the TT process). The categories are as follows:

- Interdepartmental communication is weak: Relevant information is not transferred from one department to another without solicitation.
- Interdepartmental communication is weak; only vital information is transferred from one department to another without solicitation.
- Interdepartmental communication is strong; relevant information is transferred from one department to another without solicitation.
- Interdepartmental communication is abundant and intense; Knowledge transfer is an inherent behavior in the organization.

Funding

This factor is measured by aspects related to the ease of access and level of funding for transfer activities. Leveraging the work done by Estep (2017) [1], the categories are as follows:

- No budget is allocated.
- 1% of R&D budget is allocated to TT activities.
- Between 1% and 5% of R&D budget is allocated to TT activities.
- Between 5% and 10% of R&D budget is allocated to TT activities.
- More than 10% of R&D budget is allocated to TT activities.

Absorptive Capacity

This factor is measured by aspects related to the capabilities to identify, access, and use valuable information. The categories are as follows:

- The organization does not have steady and successful partnerships, collaborative developments, or joint R&D efforts with external parties.
- The organization has one steady and successful partnership, collaborative development, or joint R&D effort per year.
- The organization has between one and three steady and successful partnerships, collaborative developments, or joint R&D efforts per year.
- The organization has between three and five steady and successful partnerships, collaborative developments, or joint R&D efforts per year.
- The organization has more than five steady and successful partnerships, collaborative developments, or joint R&D efforts per year.

Long-Range Planning

This factor is measured by aspects related to the corporate strategy and long-term technology planning. The categories are as follows:

- Corporate and business strategies are not propagated.
- Informal corporate and business strategies are tacitly propagated.
- Formal corporate and business strategies exist but are tacitly propagated.
- Formal corporate and business strategies exist and are formally propagated.
- Formal corporate and business strategies exist, are formally propagated, and employees contrast the strategies against their daily activities.

19.3.1.3 Technical Perspective

TRL Assessment

This factor is measured by aspects related to the assessment and management of technology readiness. The categories are as follows:

- No readiness assessment is conducted for the technologies being developed.
- Technology readiness is assessed, but does not inform the decision-making process in any ways.
- Technology readiness is assessed and it informs the decision-making process regarding TT mechanisms and strategies.
- Readiness assessments are conducted concerning technology (TRL) and system readiness (IRL; SRL); the assessments inform the decision-making process regarding TT mechanisms and strategies.
- Readiness assessments are conducted concerning technology (TRL), system readiness (IRL; SRL) and R&D degree of difficulty (RD3); the assessments inform the decision-making process regarding TT mechanisms and strategies.

Data Management

This factor is measured by aspects related to the standardization, acquisition, storage, recovery and analysis of a project, and technology data. The categories are as follows:

- Data on technology development is either not collected or collected in informal chats and inquiries.
- Data is collected in nonstandardized forms; the collected data varies from case to case.
- Data is collected in standardized forms; descriptive data analyses are conducted.
- Data is collected in standardized forms; descriptive data analyses are conducted; data is stored in an online repository.
- Data is collected in standardized forms; data is stored in an online repository; descriptive and predictive analyses are made based on the current and historical data.

Technology Valuation

This factor is measured by aspects related to technology assessment studies conducted at several different points throughout the technology development cycle. The categories are as follows:

- No technology assessment studies are conducted throughout the technology development cycle.
- One technology assessment study is conducted throughout the technology development cycle.
- Two technology assessment studies are conducted throughout the technology development cycle.
- Three technology assessment studies are conducted throughout the technology development cycle.
- More than three technology assessment studies are conducted throughout the technology development cycle.

Proposal Assessment

This factor is measured by aspects related to the assessment and management of research proposals. The categories are as follows:

- Research proposals are not methodically assessed.
- Research proposals are methodically and qualitatively assessed.
- Research proposals are methodically and quantitatively assessed.
- Research proposals are methodically and quantitatively assessed through more than one method.
- Research proposals are methodically and quantitatively assessed through more than two methods.

19.3.1.4 Process Perspective

Benefit Management

This factor is measured by aspects related to the identification, understanding, description, classification, and monitoring of benefits. The categories are as follows:

- Project deliverables are seen as benefits.
- Project deliverables and end products are differentiated.
- Benefits are classified, quantified, and monitored.
- Postproject benefit reviews are conducted, and the reviews inform analyses of new proposals.

Risk Management

This factor is measured by aspects related to the identification, understanding, description, classification, and monitoring of risks and opportunities. The categories are as follows:

- The project management perspective of risk is seen as enough.
- The TT risks and opportunities are identified.
- The TT risks and opportunities are identified and quantified.
- The TT risks and opportunities are actively managed. Backup plans are devised (risks); follow-on research plan and engagement with external parties are made (opportunities).

Outcomes and Decisions

This factor is measured by aspects related to the discussions, reports, and decisions made out of the TT process. The categories are as follows:

- No reports are produced and no decisions are made out of the TT process.
- Nonstandardized reports are produced; recommendations are made based on the individual's "gut feeling".
- Standardized reports are produced for every project; Go/no go decisions are made based on TT data.
- Project managers and portfolio managers consult with the TT team and use TT data before any major decision.
- TT team approval is required for every major decision on technology development projects.

TT Mechanisms Management

This factor is measured by aspects related to the identification, understanding, description, classification, and monitoring of potential TT mechanisms. The categories are as follows:

- Mechanisms are not identified or planned for before the technology is ready.
- For each project, one TT mechanism is chosen ahead of time and a plan based on the mechanism is devised.
- For each project, two TT mechanisms are chosen ahead of time and a plan for each mechanism is devised.
- For each project, three TT mechanisms are chosen ahead of time and a plan for each mechanism is devised.
- For each project, more than three TT mechanisms are chosen ahead of time and a plan for each mechanism is devised.

19.3.1.5 Strategic Alignment Perspective

Value, Impact, and Applicability Management

This factor is measured by aspects related to the economic value and strategic fit; level of impact of daily operations and beyond; and ease of applicability and extra requirements. The categories are as follows:

- No assessment is made throughout the technology development cycle.
- One assessment is made at the project start.
- Two assessments are made at the project start and end.
- Three assessments are made at the project start, midpoint, and end.
- More than three assessments are made.

Business Plan and Use Case

This factor is measured by aspects related to the planning of the technology application based on benefits, value, impact, and applicability. Leveraging the work done by Estep (2017) [1], the categories are as follows:

- The organization does not create use cases for its technologies.
- Uses cases are available, but it only has little of the required information.
- Uses cases are available, but it only has some of the required information.
- Uses cases are available, and it has most of the required information.
- Uses cases are available, and it has all the required information.

TT Planning, Control, and Flexibility

This factor is measured by aspects related to the continuous improvement of the TT process. Meetings, planning, reviews, setting objectives and priorities, and adjusting those based on the market and strategy changes. The categories are as follows:

- No review and control efforts are made.
- Annual meetings are conducted to: review the process against strategic management guidelines; set priorities and objectives; and identify and reflect on "lessons learned".
- Quarterly meetings are conducted to: review the process against strategic management guidelines; set priorities and objectives; and identify and reflect on "lessons learned".
- Monthly meetings are conducted to: review the process against strategic management guidelines; set priorities and objectives; and identify and reflect on "lessons learned".

- Weekly meetings are conducted to: review the process against strategic management guidelines; set priorities and objectives; and identify and reflect on "lessons learned".

Continuity of TT Process

This factor is measured by aspects related to the comprehensiveness of the TT process. The categories are as follows:

- TT process starts after the technology development project is finished.
- TT process starts at very late stages of the technology development project.
- TT process starts around the midpoint of the technology development project.
- TT process starts at very early stages of the technology development project.
- TT process starts even before the technology development project starts during the proposals and ideas assessment phase.

Parallel Processes Integration

This factor is measured by aspects related to the integration, feedback, and information exchange from and to other managerial processes. The categories are as follows:

- TT process is conducted completely isolated from other managerial processes.
- TT process exchanges information with project management; stage-gate decisions take the TT perspective into account.
- TT process exchanges information with the project management and roadmapping; stage-gate decisions take the TT perspective into account; roadmaps are changed to reflect TT transfer results/achievements.
- TT process exchanges information with the project management, roadmapping and portfolio management; stage-gate decisions take the TT perspective into account; roadmaps are changed to reflect TT transfer results/achievements; portfolio management receives input from the TT process, aiming for a balanced TT portfolio (in terms of mechanisms, time, and resources).

19.3.2 Expert Panel Formation

Experts were identified based on their skills and exposure to technology management and technology transfer concepts and invited to participate in the expert panels. One expert panel (EP1, composed of eight members) was used for all purposes of model validation and model quantification. Table 19.5 summarizes the expert panel formation and the research instruments used to engage them.

Table 19.5 Expert panel summary

Expert panel	Research instrument	Research instrument medium	Research instrument purpose	Number of experts
EP1	RI1	Qualtrics®	Perspective validation	8
EP1	RI2	Qualtrics®	Factors validation	8
EP1	RI3	Qualtrics®	Desirability metrics validation	8
EP1	RI4	HDM® software	Perspective quantification	8
EP1	RI5	HDM® software	Factors quantification	8
EP1	RI6	Qualtrics®	Desirability values quantification	8

Table 19.6 Perspective validation results

Perspective	No. of experts that agreed	No. of experts that disagreed	Total no. of experts	% of YES
HR and stakeholders	8	0	8	100
Organizational	8	0	8	100
Technical	8	0	8	100
Process	8	0	8	100
Strategic alignment	8	0	8	100

19.3.3 Model Validation

19.3.3.1 Perspective Validation

In order to validate the perspectives, a minimum of two-thirds (67%) acceptance rate was used. If less than 67% of the experts agreed on a certain perspective, then it would be removed from the model. The survey instrument (using Qualtrics) was sent to all of the experts, and 100% of them accepted the proposed perspectives, as shown in Table 19.6. As a result, all five original perspectives were kept.

19.3.3.2 Factor Validation

In order to validate the factors under each perspective, a minimum of two-thirds (67%) acceptance rate was used. If less than 67% of the experts agreed on a certain factor, then it would be removed from the model. The survey instrument (using Qualtrics) was sent to all experts, and the results are shown in Tables 19.7, 19.8, 19.9, 19.10, and 19.11. As a result, all original factors were kept.

Table 19.7 Factor validation results for "HR and stakeholders"

Perspective	Factor	No. of experts that agreed	No. of experts that disagreed	Total no. of experts	% of YES
HR and stakeholders	TT team and training	8	0	8	100
	TT ecosystem mgmt	7	1	8	87.5
	Stakeholders mgmt	8	0	8	100
	Senior mgmt involvement	8	0	8	100

Table 19.8 Factor validation results for "Organizational"

Perspective	Factor	No. of experts that agreed	No. of experts that disagreed	Total no. of experts	% of YES
Organizational	Communication and knowledge mgmt	7	1	8	87.5
	Funding	8	0	8	100
	Absorptive capacity	8	0	8	100
	Long-range planning	8	0	8	100

Table 19.9 Factor validation results for "technical"

Perspective	Factor	No. of experts that agreed	No. of experts that disagreed	Total no. of experts	% of YES
Technical	TRL assessment	8	0	8	100
	Data mgmt	7	1	8	87.5
	Technology valuation	8	0	8	100
	Proposal assessment	8	0	8	100

Table 19.10 Factor validation results for "process"

Perspective	Factor	No. of experts that agreed	No. of experts that disagreed	Total no. of experts	% of YES
Process	Benefit mgmt	8	0	8	100
	Risk mgmt	8	0	8	100
	Outcomes and decisions	8	0	8	100
	TT mechanisms mgmt	8	0	8	100

Table 19.11 Factor validation results for "strategic alignment"

Perspective	Factor	No. of experts that agreed	No. of experts that disagreed	Total no. of experts	% of YES
Strategic alignment	Value, impact, and applicability mgmt	8	0	8	100
	Business plan and use case	8	0	8	100
	TT planning, control, and flexibility	7	1	8	87.5
	Continuity of TT process	7	1	8	87.5
	Parallel processes integration	8	0	8	100

19.3.3.3 Desirability Metrics Validation

In order to validate the levels (metrics) to measure the desirability of each factor, a minimum of two-thirds (67%) acceptance rate was used. If less than 67% of the experts agreed on a certain metric, then it would be removed from the model. The survey instrument (using Qualtrics) was sent to all experts, and the results are shown in Tables 19.12, 19.13, 19.14, 19.15, 19.16, 19.17, 19.18, 19.19, 19.20, 19.21, 19.22, 19.23, 19.24, 19.25, 19.26, 19.27, 19.28, 19.29, 19.30, 19.31 and 19.32. As a result, all original metrics were kept.

Perspective: HR and Stakeholders

Table 19.12 Desirability metrics validation results for "TT team and training"

Metric	Agreed	Disagreed	Total	% of YES
No dedicated TT team and no training	8	0	8	100
Dedicated TT team; not multidisciplinary; no training	8	0	8	100
Dedicated TT team; slightly multidisciplinary (with representatives from more than one department); either no training or informal training	8	0	8	100
Dedicated TT team; multidisciplinary (with representatives from all relevant departments); formal training	8	0	8	100
Dedicated TT team; multidisciplinary (with representatives from all relevant departments); formal periodic training (quarterly-based or more often)	7	1	8	87.5

Table 19.13 Desirability metrics validation results for "TT Ecosystem Mgmt"

Metric	Agreed	Disagreed	Total	% of YES
No interaction with TT ecosystem entities whatsoever	8	0	8	100
Sparse interaction with TT ecosystem (less than monthly); no cooperation	8	0	8	100
Frequent interaction (at least monthly); no cooperation	8	0	8	100
Frequent interaction (at least monthly); formal agreement with some TT ecosystem entities (up to three)	8	0	8	100
Frequent interaction (at least monthly) and formal agreement with multiple TT ecosystem entities (more than three)	8	0	8	100

Table 19.14 Desirability metrics validation results for “Stakeholders Mgmt”

Metric	Agreed	Disagreed	Total	% of YES
TT process is limited to the TT team alone; no one else participates.	8	0	8	100
TT team has sparse contact (less than monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders, but with solicitation).	8	0	8	100
TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders, but with solicitation).	7	1	8	87.5
TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders and without solicitation).	8	0	8	100
TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes both ways (from and to stakeholders).	8	0	8	100

Table 19.15 Desirability metrics validation results for “Senior mgmt. involvement”

Metric	Agreed	Disagreed	Total	% of YES
There is no senior management interest in the process	8	0	8	100
TT process is supported by middle management, but their engagement is not consistent	7	1	8	87.5
Middle management is actively engaged in the TT process, but senior management still does not openly support it	7	1	8	87.5
Senior management is aware of the TT process, but their engagement is not consistent	8	0	8	100
There is evidence of consistent engagement and support for the TT process at all levels of the organization	8	0	8	100

Perspective: Organizational

Table 19.16 Desirability metrics validation results for "Communication and Knowledge Mgmt"

Metric	Agreed	Disagreed	Total	% of YES
Interdepartmental communication is weak; relevant information is not transferred from one department to another without solicitation	8	0	8	100
Interdepartmental communication is weak; only vital information is transferred from one department to another without solicitation	8	0	8	100
Interdepartmental communication is strong; relevant information is transferred from one department to another without solicitation	8	0	8	100
Interdepartmental communication is abundant and intense; knowledge transfer is an inherent behavior in the organization	8	0	8	100

Table 19.17 Desirability metrics validation results for "Funding"

Metric	Agreed	Disagreed	Total	% of YES
No budget is allocated	8	0	8	100
1% of R&D budget is allocated to TT activities	8	0	8	100
Between 1% and 5% of R&D budget is allocated to TT activities	8	0	8	100
Between 5% and 10% of R&D budget is allocated to TT activities	8	0	8	100
More than 10% of R&D budget is allocated to TT activities	8	0	8	100

Table 19.18 Desirability metrics validation results for "Absorptive Capacity"

Metric	Agreed	Disagreed	Total	% of YES
The organization does not have steady and successful partnerships, collaborative developments, or joint R&D efforts with external parties	8	0	8	100
The organization has one steady and successful partnership, collaborative development, or joint R&D effort per year	8	0	8	100
The organization has between one and three steady and successful partnerships, collaborative developments, or joint R&D efforts per year	8	0	8	100
The organization has between three and five steady and successful partnerships, collaborative developments, or joint R&D efforts per year	8	0	8	100
The organization has more than five steady and successful partnerships, collaborative developments, or joint R&D efforts per year	8	0	8	100

Table 19.19 Desirability metrics validation results for "Long-range Planning"

Metric	Agreed	Disagreed	Total	% of YES
Corporate and business strategies are not propagated	8	0	8	100
Informal corporate and business strategies are tacitly propagated	8	0	8	100
Formal corporate and business strategies exist but are tacitly propagated	8	0	8	100
Formal corporate and business strategies exist and are formally propagated	8	0	8	100
Formal corporate and business strategies exist, are formally propagated, and employees contrast the strategies against their daily activities	8	0	8	100

Perspective: Technical

Table 19.20 Desirability metrics validation results for "TRL Assessment"

Metric	Agreed	Disagreed	Total	% of YES
No readiness assessment is conducted for the technologies being developed	8	0	8	100
Technology readiness is assessed, but does not inform the decision-making process in any ways	8	0	8	100
Technology readiness is assessed and it informs the decision-making process regarding TT mechanisms and strategies	8	0	8	100
Readiness assessments are conducted concerning technology (TRL) and system readiness (IRL; SRL); the assessments inform the decision-making process regarding TT mechanisms and strategies	8	0	8	100
Readiness assessments are conducted concerning technology (TRL), system readiness (IRL; SRL) and R&D degree of difficulty (RD3); the assessments inform the decision-making process regarding TT mechanisms and strategies	8	0	8	100

Table 19.21 Desirability metrics validation results for "Data Management"

Metric	Agreed	Disagreed	Total	% of YES
Data on technology development is either not collected or collected in informal chats and inquiries	8	0	8	100
Data is collected in nonstandardized forms; collected data varies from case to case	8	0	8	100
Data is collected in standardized forms; descriptive data analyses are conducted	8	0	8	100
Data is collected in standardized forms; descriptive data analyses are conducted; data is stored in an online repository	8	0	8	100
Data is collected in standardized forms; data is stored in an online repository; descriptive and predictive analyses are made based on current and historical data	8	0	8	100

Table 19.22 Desirability metrics validation results for "Technology Valuation"

Metric	Agreed	Disagreed	Total	% of YES
No technology assessment studies are conducted throughout the technology development cycle	8	0	8	100
One technology assessment study is conducted throughout the technology development cycle	8	0	8	100
Two technology assessment studies are conducted throughout the technology development cycle	8	0	8	100
Three technology assessment studies are conducted throughout the technology development cycle	8	0	8	100
More than three technology assessment studies are conducted throughout the technology development cycle	8	0	8	100

Table 19.23 Desirability metrics validation results for "Proposal Assessment"

Metric	Agreed	Disagreed	Total	% of YES
Research proposals are not methodically assessed	8	0	8	100
Research proposals are methodically and qualitatively assessed	8	0	8	100
Research proposals are methodically and quantitatively assessed	8	0	8	100
Research proposals are methodically and quantitatively assessed through more than one method	8	0	8	100
Research proposals are methodically and quantitatively assessed through more than two methods	8	0	8	100

Perspective: Process

Table 19.24 Desirability metrics validation results for "Benefit Management"

Metric	Agreed	Disagreed	Total	% of YES
Project deliverables are seen as benefits	8	0	8	100
Project deliverables and end products are differentiated	8	0	8	100
Benefits are classified, quantified, and monitored	8	0	8	100
Postproject benefit reviews are conducted and the reviews inform analyses of new proposals	8	0	8	100

Table 19.25 Desirability metrics validation results for "Risk Management"

Metric	Agreed	Disagreed	Total	% of YES
The project management perspective of risk is seen as enough	8	0	8	100
The TT risks and opportunities are identified	8	0	8	100
The TT risks and opportunities are identified and quantified	8	0	8	100
The TT risks and opportunities are actively managed; backup plans are devised (risks); and follow-on research plan and engagement with external parties are made (opportunities)	8	0	8	100

Table 19.26 Desirability metrics validation results for "Outcomes and Decisions"

Metric	Agreed	Disagreed	Total	% of YES
No reports are produced and no decisions are made out of the TT process	8	0	8	100
Nonstandardized reports are produced; recommendations are made based on individual's "gut feeling"	8	0	8	100
Standardized reports are produced for every project; go/no go decisions are made based on TT data	8	0	8	100
Project managers and portfolio managers consult with the TT team and use TT data before any major decision	8	0	8	100
TT team approval is required for every major decision on technology development projects	8	0	8	100

Table 19.27 Desirability metrics validation results for "TT mechanisms mgmt"

Metric	Agreed	Disagreed	Total	% of YES
Mechanisms are not identified or planned for before the technology is ready	8	0	8	100
For each project, one TT mechanism is chosen ahead of time and a plan based on the mechanism is devised	8	0	8	100
For each project, two TT mechanisms are chosen ahead of time and a plan for each mechanism is devised	8	0	8	100
For each project, three TT mechanisms are chosen ahead of time and a plan for each mechanism is devised	8	0	8	100
For each project, more than three TT mechanisms are chosen ahead of time and a plan for each mechanism is devised	8	0	8	100

Perspective: Strategic Alignment

Table 19.28 Desirability metrics validation results for "Value, Impact, and Applicability Mgmt"

Metric	Agreed	Disagreed	Total	% of YES
No assessment is made throughout the technology development cycle	8	0	8	100
One assessment is made at project start	8	0	8	100
Two assessments are made at project start and end	8	0	8	100
Three assessments are made at project start, midpoint, and end	8	0	8	100
More than three assessments are made	8	0	8	100

Table 19.29 Desirability metrics validation results for "Business Plan and Use Case"

Metric	Agreed	Disagreed	Total	% of YES
The organization does not create use cases for its technologies	8	0	8	100
Use cases are available, but they only have little of the required information	8	0	8	100
Use cases are available, but they only have some of the required information	8	0	8	100
Use cases are available and they have most of the required information	8	0	8	100
Use cases are available and they have all the required information	8	0	8	100

Table 19.30 Desirability metrics validation results for "TT Planning, Control, and Flexibility"

Metric	Agreed	Disagreed	Total	% of YES
No review and control efforts are made	8	0	8	100
Annual meetings are conducted to: Review the process against strategic management guidelines; set priorities and objectives; identify and reflect on "lessons learned"	8	0	8	100
Quarterly meetings are conducted to: Review the process against strategic management guidelines; set priorities and objectives; identify and reflect on "lessons learned"	8	0	8	100
Monthly meetings are conducted to: Review the process against strategic management guidelines; set priorities and objectives; identify and reflect on "lessons learned"	8	0	8	100
Weekly meetings are conducted to: Review the process against strategic management guidelines; set priorities and objectives; identify and reflect on "lessons learned"	7	1	8	87.5

Table 19.31 Desirability metrics validation results for "Continuity of TT Process"

Metric	Agreed	Disagreed	Total	% of YES
TT process starts after the technology development project is finished	8	0	8	100
TT process starts at very late stages of the technology development project	8	0	8	100
TT process starts around the midpoint of the technology development project	8	0	8	100
TT process starts at very early stages of the technology development project	8	0	8	100
TT process starts even before the technology development project starts during the proposals and ideas assessment phase	8	0	8	100

Table 19.32 Desirability metrics validation results for "Parallel Processes Integration"

Metric	Agreed	Disagreed	Total	% of YES
TT process is conducted completely isolated from other managerial processes	8	0	8	100
TT process exchanges information with project management; stage-gate decisions take the TT perspective into account	8	0	8	100
TT process exchanges information with project management and roadmapping; stage-gate decisions take the TT perspective into account; roadmaps are changed to reflect TT transfer results/achievements	8	0	8	100
TT process exchanges information with project management, roadmapping, and portfolio management; stage-gate decisions take the TT perspective into account; roadmaps are changed to reflect TT transfer results/achievements; portfolio management receives input from the TT process, aiming for a balanced TT portfolio (in terms of mechanisms, time, and resources)	8	0	8	100

19.3.4 Validated Model

After having finalized the process of validation, the initial model was accepted in its entirety without any changes relatively to the one presented initially. The model is shown in Fig. 19.2.

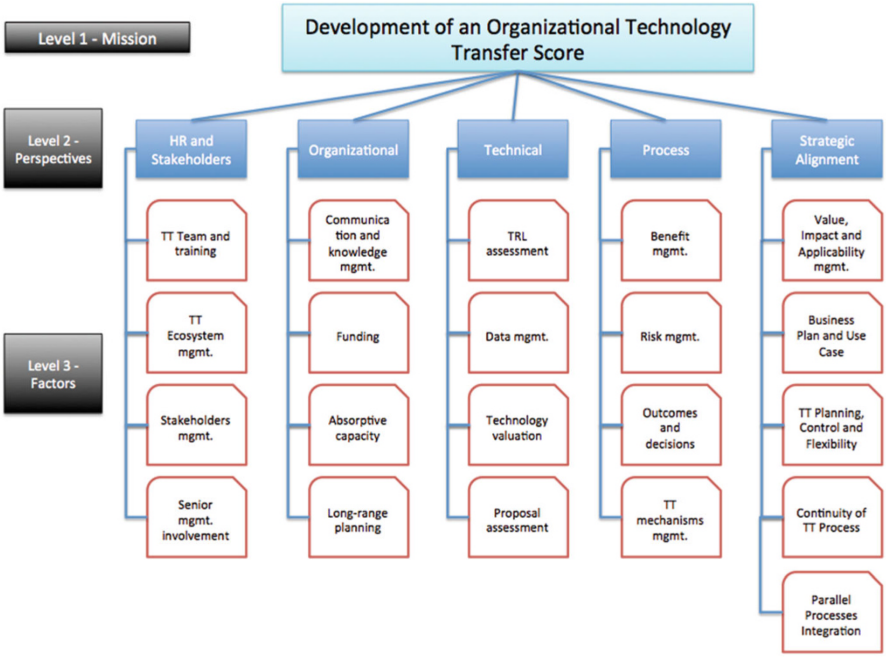

Fig. 19.2 Validated HDM model

19.3.5 *Model Quantification*

19.3.5.1 Perspective Quantification

Having confirmed every component of the model, the first step of the quantification process is for the experts to quantify the model's perspectives.

The experts' judgments were captured through pairwise comparisons utilizing the constant sum method, where each comparison is made by distributing 100 points between the pair of items being compared. The importance of each perspective relative to the determination of the TT score is obtained by the mathematical procedures explained in previous chapters. The arithmetical mean of the eight experts is used as the final result. The judgments were made using the HDM® software, which also calculated the individual logical inconsistencies and the group disagreements. As a general rule, no inconsistency or disagreement higher than 10% would be accepted. All inconsistency and disagreement levels were below the 10% mark; therefore, no further action was taken. If this were to happen, nonetheless, experts would be asked to repeat the judgments in order to decrease inconsistencies and/or disagreements to acceptable levels. In extreme cases, the possibility of removing outliers from the expert panel would be considered.

The judgments for each expert and the average for each perspective are shown in Table 19.33 and by an illustrative graph (Fig. 19.3).

As shown in Table 19.33 and Fig. 19.3, all perspectives are ranked very closely to each other. "HR and stakeholders" and "Organizational" were judged as the most important perspectives (0.21 of contribution toward determining the TT score each), closely followed by "Process" and "Strategic alignment" (0.20 each) and "Technical" (0.19).

19.3.5.2 Factor Quantification

In order to quantify the factors under each perspective, the process of perspective quantification was applied again. The experts' judgments were captured through pairwise comparisons utilizing the constant sum method, where each comparison is made by distributing 100 points between the pairs of items being compared. The importance of each perspective relative to the determination of the TT score is obtained by the mathematical procedures explained in previous chapters. The arithmetic mean of the eight experts is used as the final result. The judgments were made using the HDM® software, which also calculated the individual logical inconsistencies and the group disagreements. As a general rule, no inconsistency or disagreement higher than 10% would be accepted. All inconsistency and disagreement levels were below the 10% mark; therefore, no further action was taken. If that were to happen, nonetheless, experts would be asked to repeat the judgments in order to decrease the inconsistencies and/or disagreements to acceptable levels. In extreme cases, the possibility of removing outliers from the expert panel would be considered.

Table 19.34 and Fig. 19.4 display the judgments for each expert and the average for each factor.

As shown Table 19.34 and Fig. 19.4, "TT team and training" and "Senior management involvement" were judged as the most important perspectives (0.27 of contribution toward the HR and stakeholders perspective each), followed by "Stakeholders management" (0.25) and "TT ecosystem management" (0.20) (Table 19.35; Fig. 19.5).

As shown Table 19.35 and Fig. 19.5, "Funding" was judged as the most important perspective (0.29 of contribution toward the organizational perspective), followed by "Communication and knowledge management" (0.28), "Absorptive capacity" (0.23), and "Long-range planning" (0.20) (Table 19.36; Fig. 19.6).

As shown in Table 19.36 and Fig. 19.6, "TRL assessment" was judged as the most important perspective (0.29 of contribution toward the Technical perspective), followed by "Technology valuation" (0.26), "Data management" (0.23), and "Proposal assessment" (0.22) (Table 19.37; Fig. 19.7).

As shown in Table 19.37 and Fig. 19.7, "Risk management" was judged as the most important perspective (0.28 of contribution toward the Process perspective), followed by "Benefit management" (0.25), "TT mechanisms management" (0.24), and "Outcomes and decisions" (0.22) (Table 19.38; Fig. 19.8).

Table 19.33 Perspective quantification results

Experts (E)	HR and Stakeholders	Organizational	Technical	Process	Strategic Alignment	Inconsistency
E 1	0.23	0.23	0.18	0.16	0.20	0
E 2	0.12	0.18	0.22	0.25	0.23	0.01
E 3	0.30	0.28	0.20	0.14	0.09	0.01
E 4	0.24	0.20	0.17	0.14	0.24	0.07
E 5	0.23	0.24	0.16	0.18	0.19	0.01
E 6	0.14	0.20	0.18	0.26	0.22	0.01
E 7	0.18	0.17	0.22	0.27	0.17	0
E 8	0.21	0.19	0.16	0.18	0.26	0
Mean	0.21	0.21	0.19	0.20	0.20	–
Disagreement						0.041

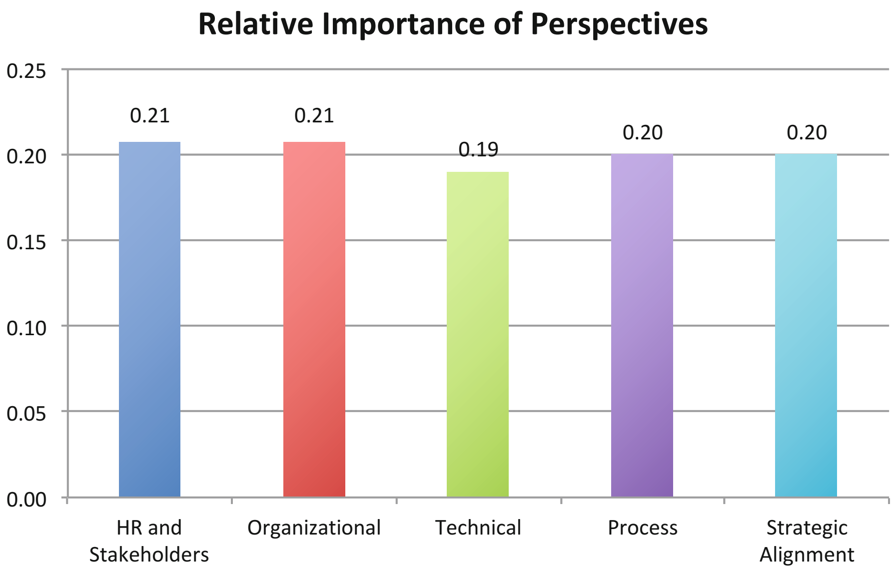

Fig. 19.3 Perspective quantification results

Table 19.34 Factor quantification results for "HR and Stakeholders"

Experts	TT team and training	TT ecosystem mgmt	Stakeholders mgmt	Senior mgmt involvement	Inconsistency
E 1	0.33	0.18	0.22	0.27	0.01
E 2	0.14	0.15	0.27	0.44	0.01
E 3	0.43	0.24	0.15	0.17	0.01
E 4	0.30	0.21	0.23	0.26	0
E 5	0.23	0.19	0.29	0.29	0
E 6	0.32	0.19	0.28	0.21	0
E 7	0.21	0.26	0.26	0.26	0
E 8	0.21	0.18	0.32	0.28	0
Mean	0.27	0.20	0.25	0.27	–
Disagreement					0.055

As shown in Table 19.38 and Fig. 19.8, "Value, impact, and applicability management" was judged as the most important perspective (0.26 of contribution toward the Strategic Alignment perspective), followed by "TT planning, control and flexibility" (0.21), "Business plan and use case" (0.20), and "Continuity of TT process" and "Parallel processes integration" (0.17 each).

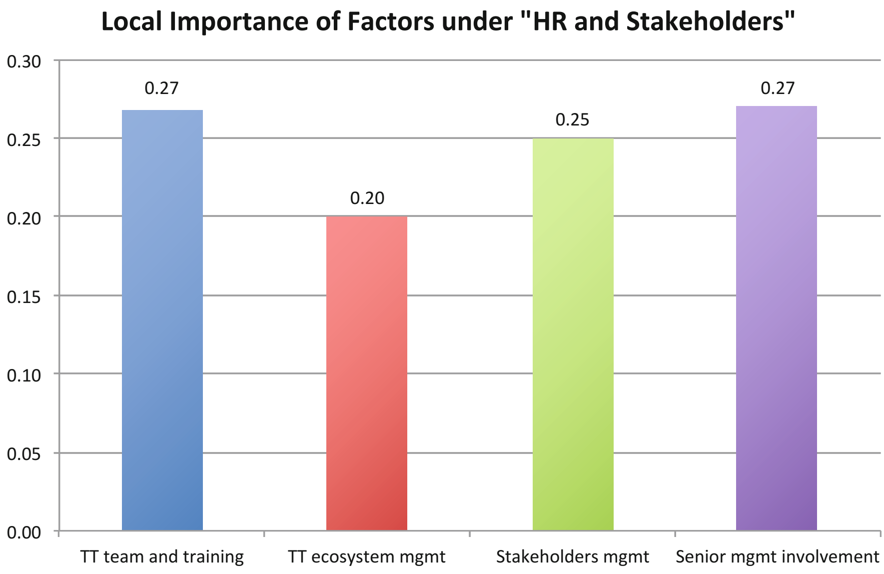

Fig. 19.4 Factor quantification results for “HR and Stakeholders”

Table 19.35 Factor quantification results for “Organizational”

Experts	Communication and knowledge mgmt	Funding	Absorptive capacity	Long-range planning	Inconsistency
E 1	0.23	0.32	0.27	0.18	0
E 2	0.36	0.27	0.21	0.16	0
E 3	0.35	0.25	0.23	0.17	0
E 4	0.28	0.28	0.21	0.22	0
E 5	0.24	0.40	0.16	0.20	0
E 6	0.27	0.21	0.33	0.19	0.01
E 7	0.23	0.31	0.23	0.23	0
E 8	0.29	0.26	0.23	0.21	0
Mean	0.28	0.29	0.23	0.20	–
Disagreement					0.04

19.3.5.3 Summary of Model Quantification

Table 19.39 summarizes the weights obtained for the perspectives and factors through the experts’ judgments. The table includes local and global importance values for each factor.

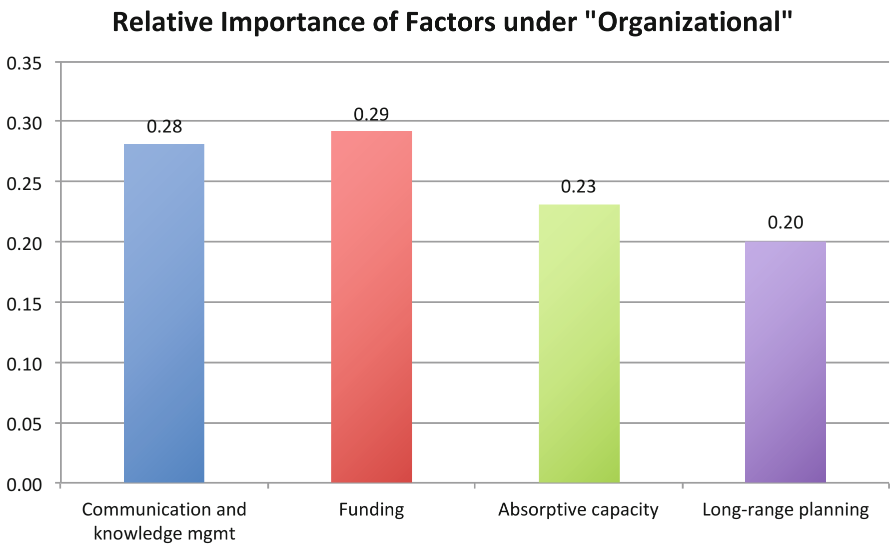

Fig. 19.5 Factor quantification results for “Organizational”

Table 19.36 Factor quantification results for “Technical”

Experts	TRL assessment	Data mgmt	Technology valuation	Proposal assessment	Inconsistency
E 1	0.29	0.21	0.31	0.19	0
E 2	0.38	0.26	0.21	0.14	0
E 3	0.29	0.14	0.33	0.24	0.01
E 4	0.23	0.23	0.29	0.25	0
E 5	0.23	0.35	0.23	0.19	0
E 6	0.33	0.21	0.20	0.26	0
E 7	0.25	0.20	0.24	0.31	0
E 8	0.30	0.22	0.27	0.21	0
Mean	0.29	0.23	0.26	0.22	–
Disagreement					0.046

19.3.5.4 Desirability Value Quantification

The experts were also prompted to quantify the levels of desirability for each factor, thereby enabling the establishment of desirability curves. Following previous research [16, 17], the average value of experts’ judgments was considered the final value for the curve creation. Following are the respective expert judgments along

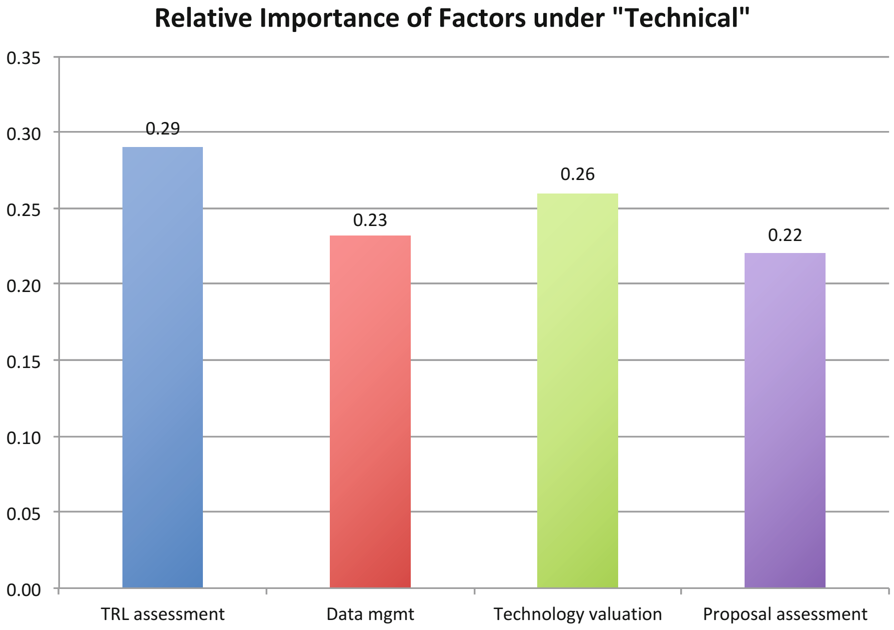

Fig. 19.6 Factor quantification results for “Technical”

Table 19.37 Factor quantification results for “Process”

Experts	Benefit mgmt	Risk mgmt	Outcomes and decisions	TT mechanisms mgmt	Inconsistency
E 1	0.21	0.26	0.33	0.20	0.01
E 2	0.29	0.14	0.19	0.37	0.02
E 3	0.23	0.34	0.16	0.27	0.01
E 4	0.25	0.30	0.21	0.25	0.01
E 5	0.26	0.32	0.21	0.21	0
E 6	0.27	0.33	0.21	0.19	0.01
E 7	0.26	0.28	0.25	0.22	0
E 8	0.26	0.30	0.23	0.21	0
Mean	0.25	0.28	0.22	0.24	
Disagreement					0.039

with the mean values and the curves for each factor (Figs. 19.9, 19.10, 19.11, 19.12, 19.13, 19.14, 19.15, 19.16, 19.17, 19.18, 19.19, 19.20, 19.21, 19.22, 19.23, 19.24, 19.25, 19.26, 19.27, 19.28, and 19.29; Tables 19.40, 19.41, 19.42, 19.43, 19.44, 19.45, 19.46, 19.47, 19.48, 19.49, 19.50, 19.51, 19.52, 19.53, 19.54, 19.55, 19.56, 19.57, 19.58, 19.59, and 19.60).

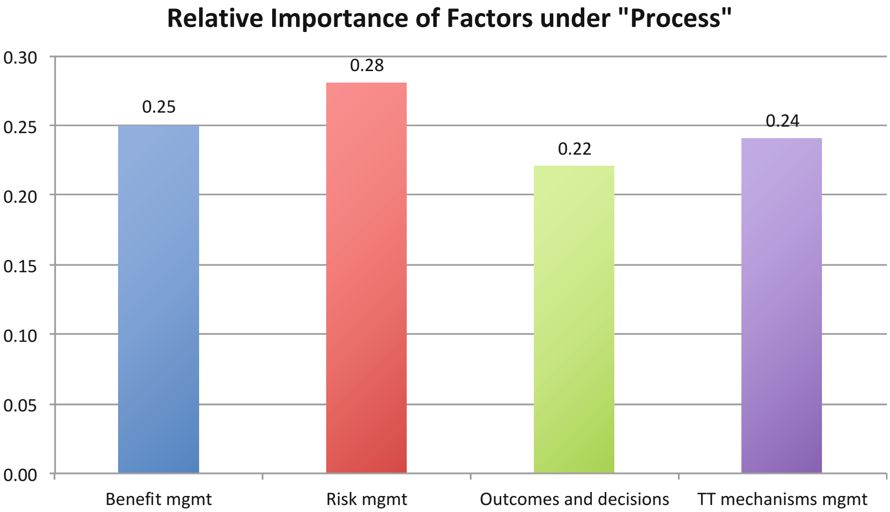

Fig. 19.7 Factor quantification results for "Process"

Table 19.38 Factor quantification results for "Strategic Alignment"

Experts	Value, impact and applicability mgmt	Business plan and use case	TT planning, control, and flexibility	Continuity of TT process	Parallel processes integration	Inconsistency
E 1	0.31	0.13	0.18	0.18	0.20	0.01
E 2	0.31	0.24	0.22	0.12	0.11	0.01
E 3	0.26	0.27	0.21	0.15	0.10	0.01
E 4	0.20	0.17	0.22	0.21	0.21	0.01
E 5	0.27	0.22	0.18	0.18	0.15	0
E 6	0.27	0.19	0.23	0.14	0.17	0.01
E 7	0.20	0.16	0.23	0.19	0.22	0
E 8	0.24	0.22	0.20	0.15	0.18	0
Mean	0.26	0.20	0.21	0.17	0.17	
Disagreement						0.033

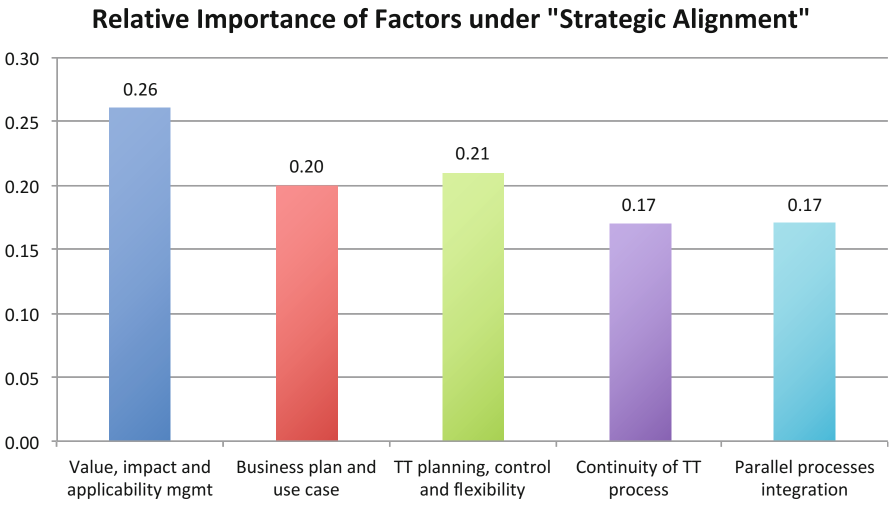

Fig. 19.8 Factor quantification results for "Strategic Alignment"

Table 19.39 Summary of perspectives and factor quantification

Perspectives		Factors		
Name	Value	Name	Local value	Global value
HR and stakeholders	0.21	TT team and training	0.27	0.06
		TT ecosystem mgmt	0.20	0.04
		Stakeholders mgmt	0.25	0.05
		Senior mgmt involvement	0.27	0.06
Organizational	0.21	Communication and knowledge mgmt	0.28	0.06
		Funding	0.29	0.06
		Absorptive capacity	0.23	0.05
		Long-range planning	0.20	0.04
Technical	0.19	TRL assessment	0.29	0.05
		Data mgmt	0.23	0.04
		Technology valuation	0.26	0.05
		Proposal assessment	0.22	0.04
Process	0.20	Benefit mgmt	0.25	0.05
		Risk mgmt	0.28	0.06
		Outcomes and decisions	0.22	0.04
		TT mechanisms mgmt	0.24	0.05
Strategic alignment	0.20	Value, impact, and applicability mgmt	0.26	0.05
		Business plan and use case	0.20	0.04
		TT planning, control, and flexibility	0.21	0.04
		Continuity of TT process	0.17	0.03
		Parallel processes integration	0.17	0.03

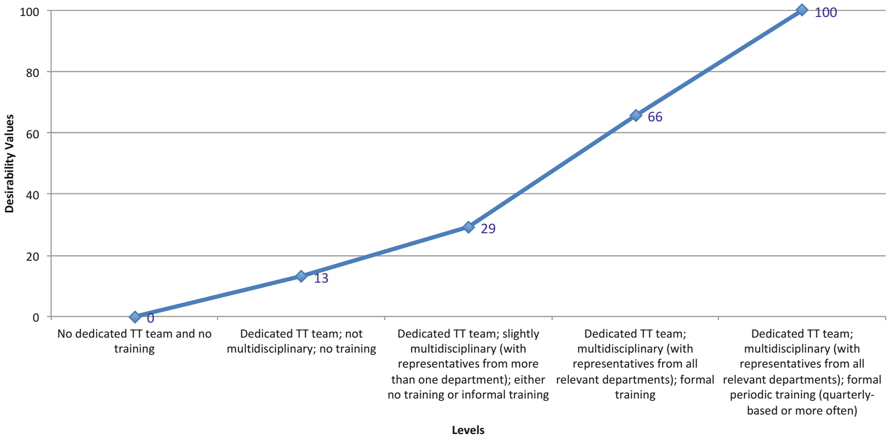

Fig. 19.9 Desirability curve for "TT Team and Training"

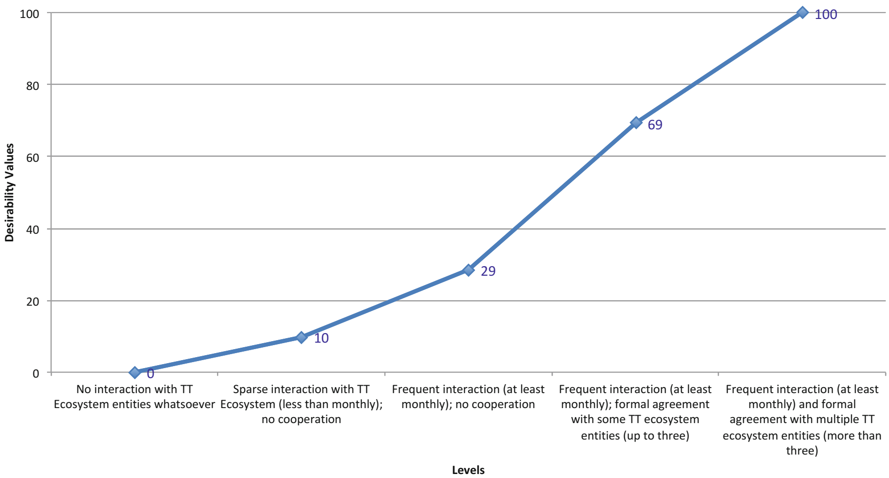

Fig. 19.10 Desirability curve for "TT Ecosystem Mgmt"

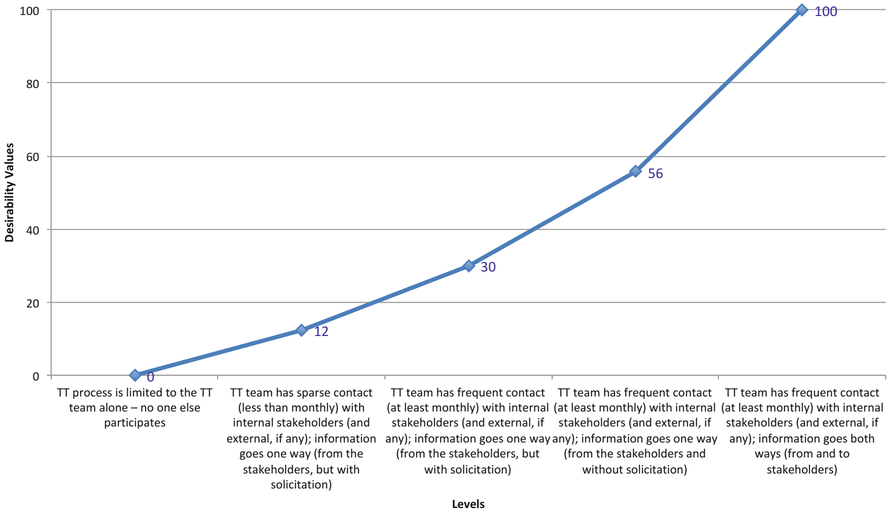

Fig. 19.11 Desirability curve for "Stakeholders Mgmt"

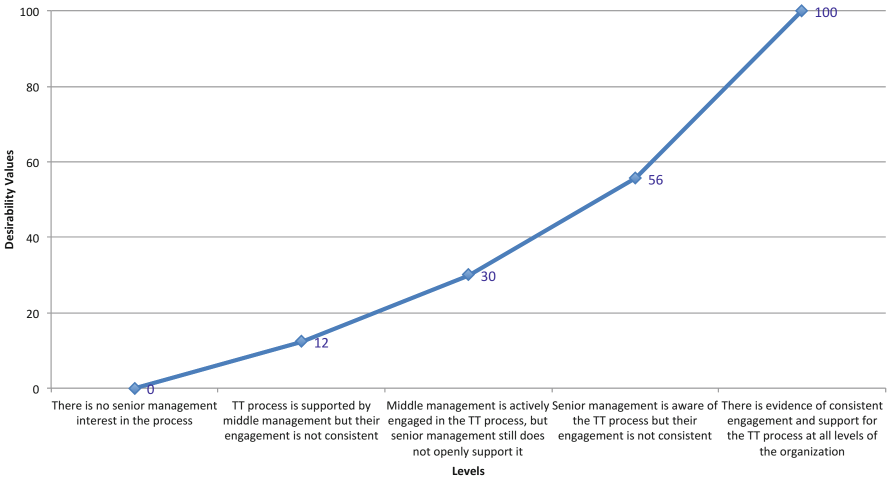

Fig. 19.12 Desirability curve for "Senior Mgmt. Involvement"

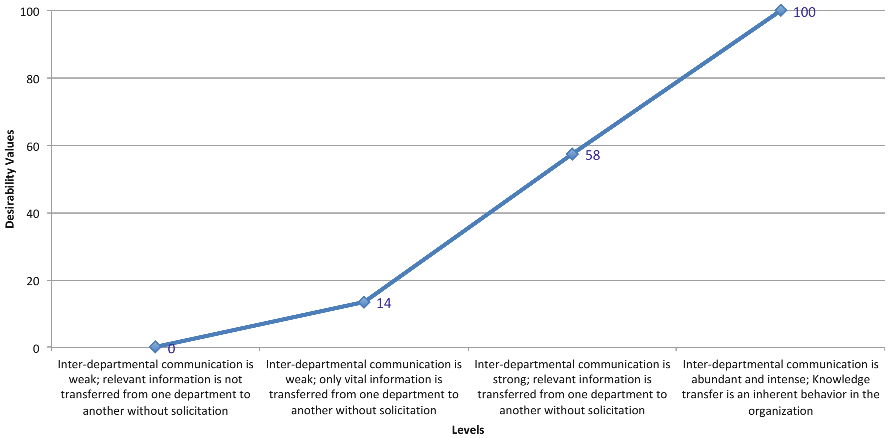

Fig. 19.13 Desirability curve for "Communication and Knowledge Mgmt"

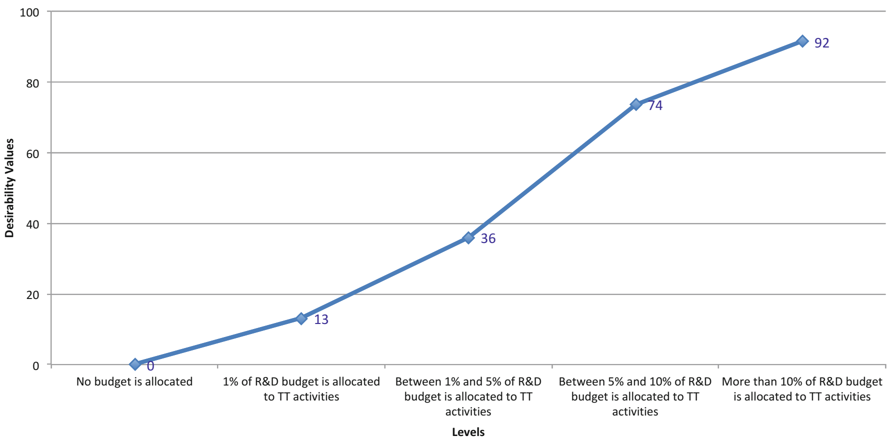

Fig. 19.14 Desirability curve for "Funding"

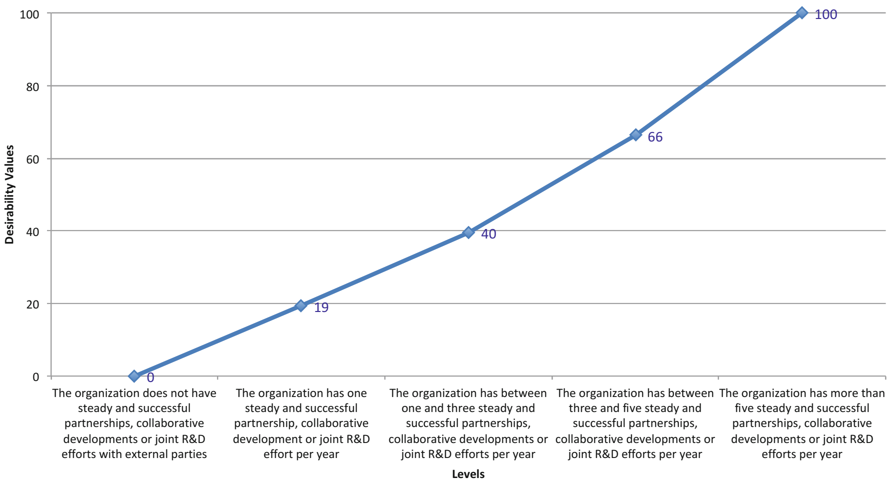

Fig. 19.15 Desirability curve for "Absorptive Capacity"

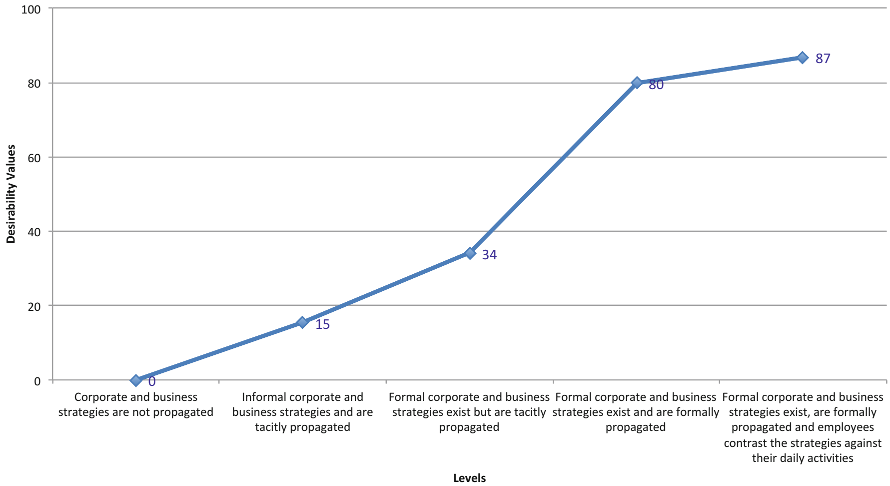

Fig. 19.16 Desirability curve for "Long-range Planning"

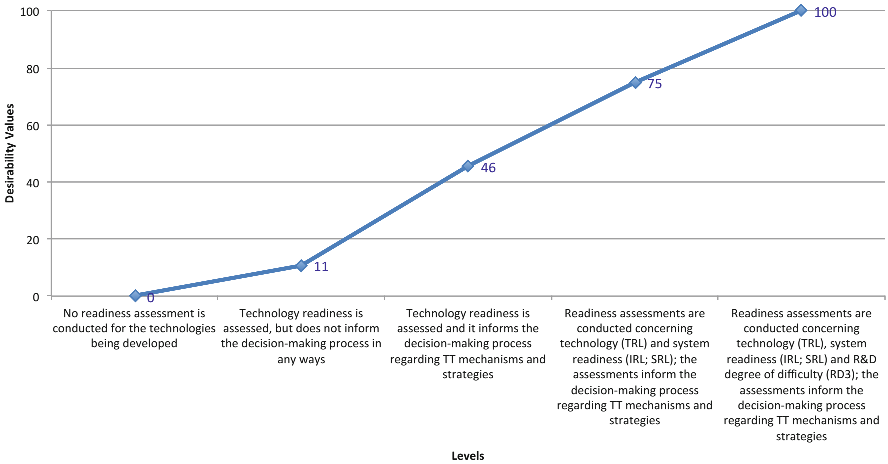

Fig. 19.17 Desirability curve for "TRL Assessment"

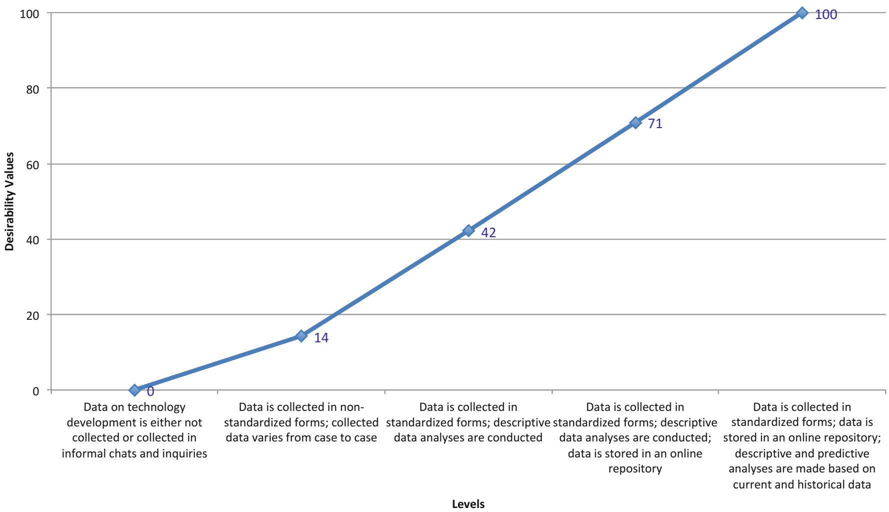

Fig. 19.18 Desirability curve for "Data Management"

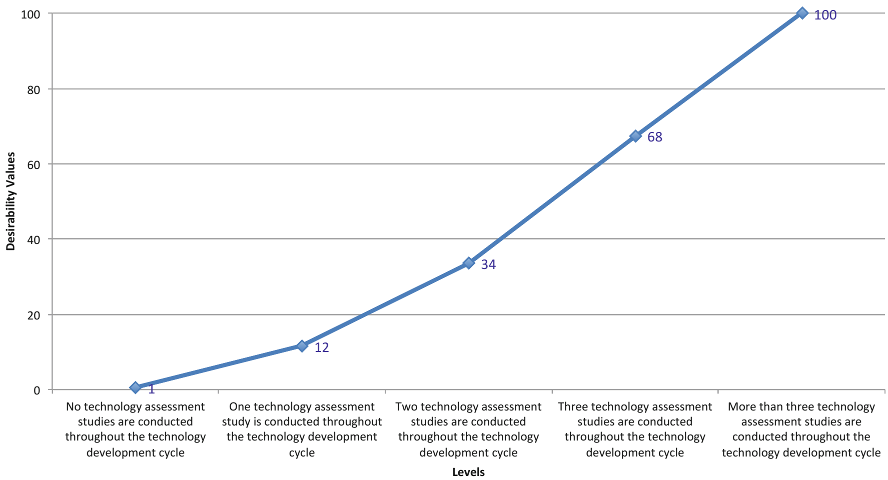

Fig. 19.19 Desirability curve for "Technology Valuation"

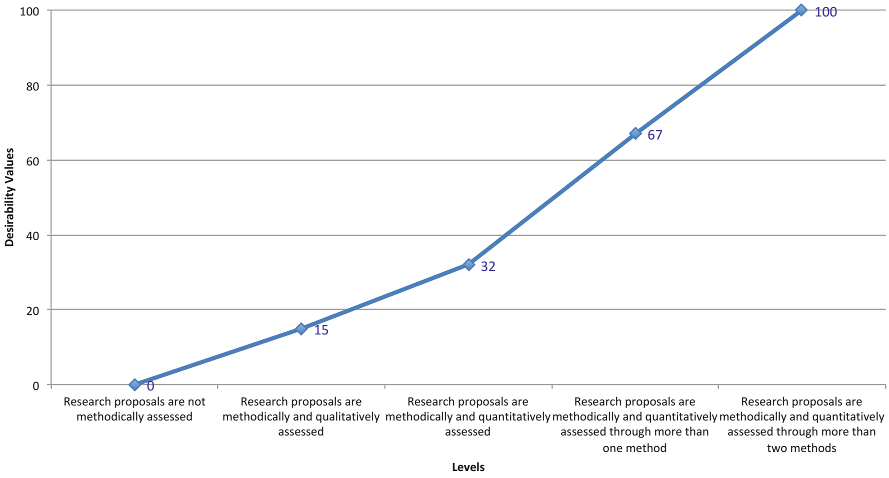

Fig. 19.20 Desirability curve for "Proposal Assessment"

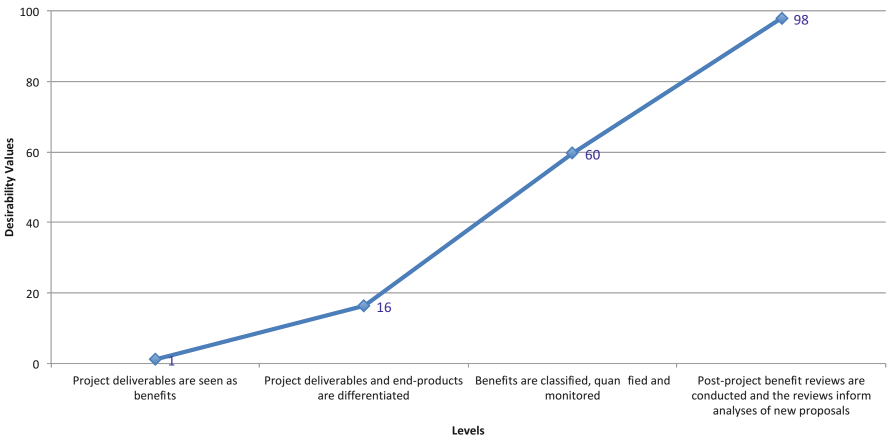

Fig. 19.21 Desirability curve for "Benefit Management"

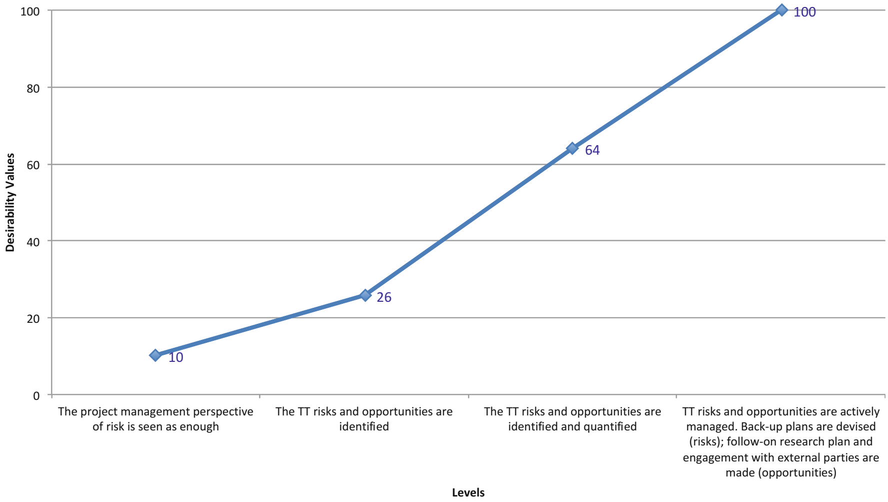

Fig. 19.22 Desirability curve for "Risk Management"

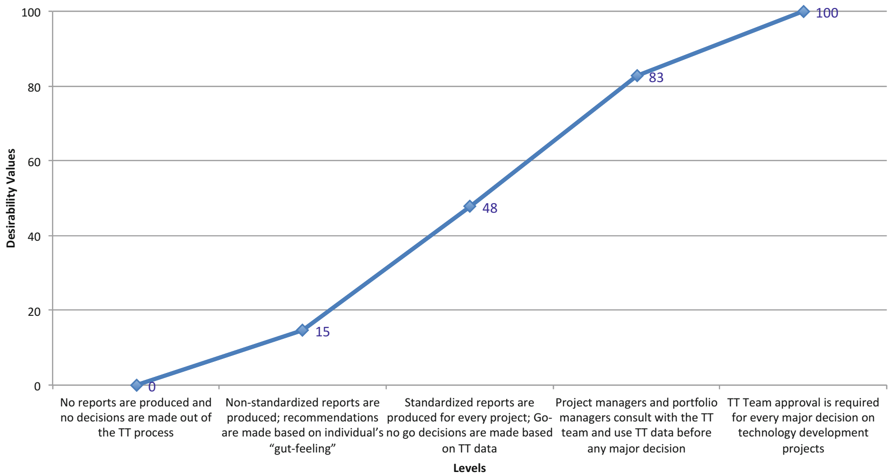

Fig. 19.23 Desirability curve for "Outcomes and Decisions"

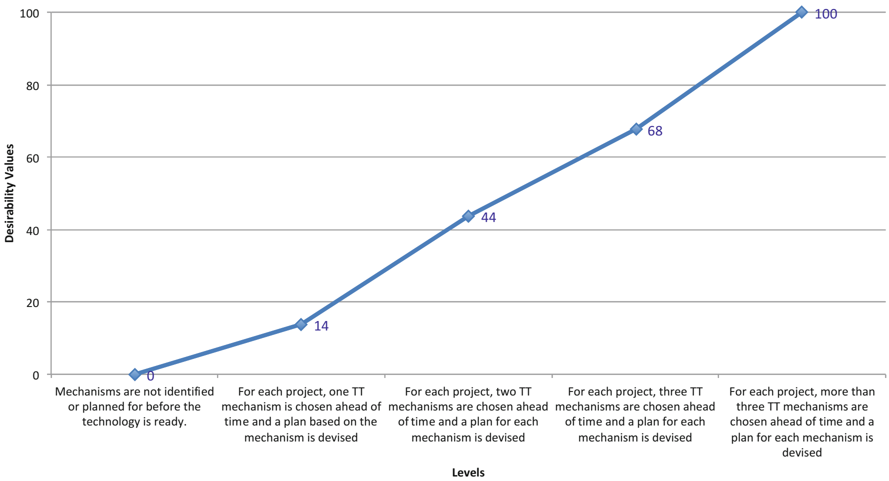

Fig. 19.24 Desirability curve for "TT Mechanisms Mgmt"

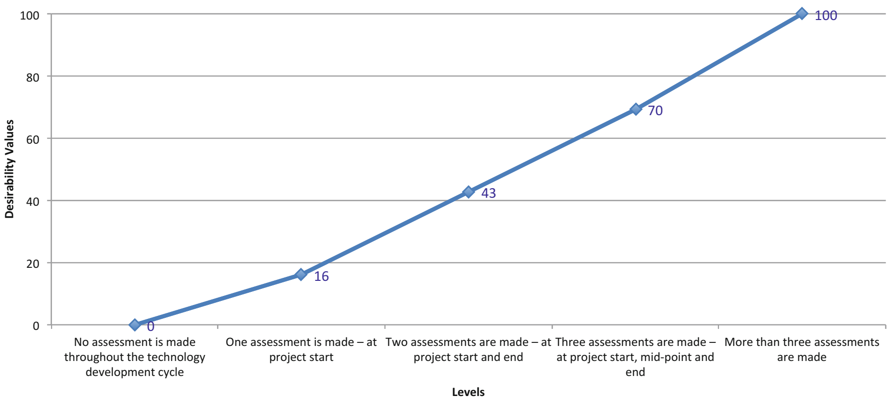

Fig. 19.25 Desirability curve for "Value, Impact, and Applicability Mgmt"

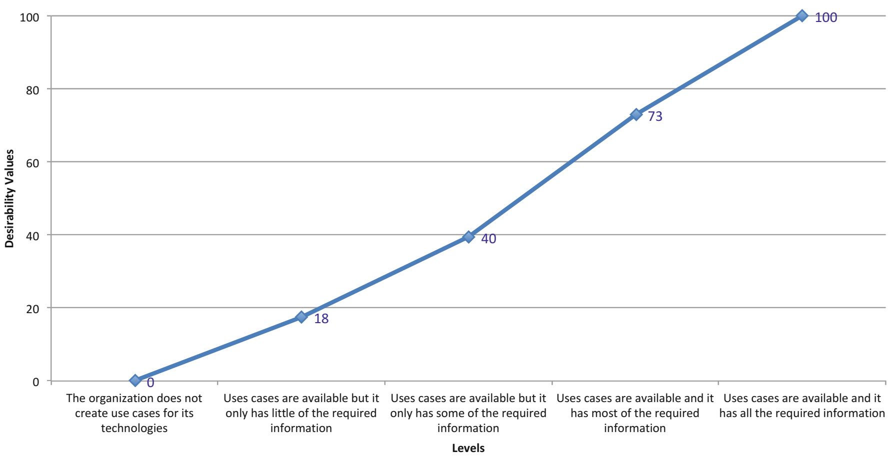

Fig. 19.26 Desirability curve for "Business Plan and Use Case"

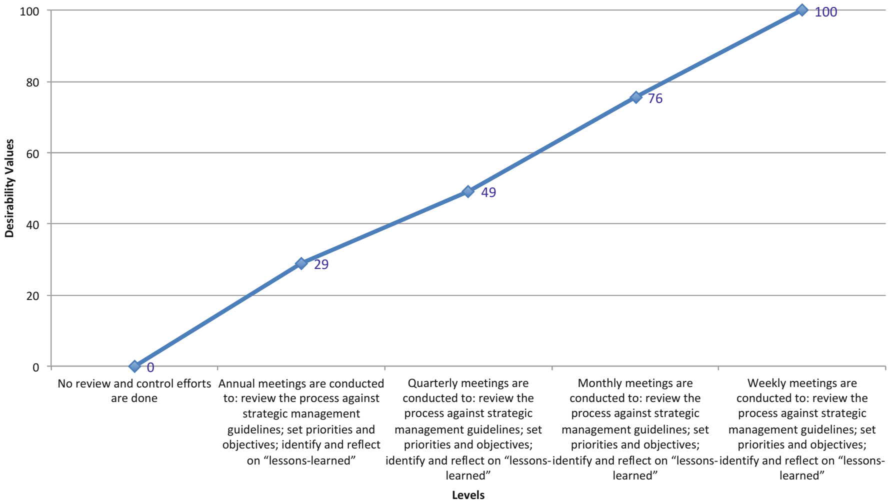

Fig. 19.27 Desirability curve for "TT planning, control, and flexibility"

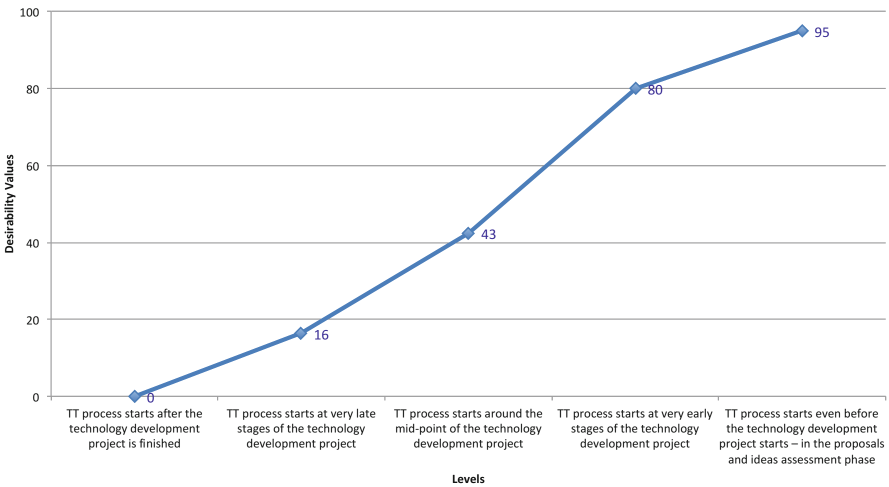

Fig. 19.28 Desirability curve for "Continuity of TT process"

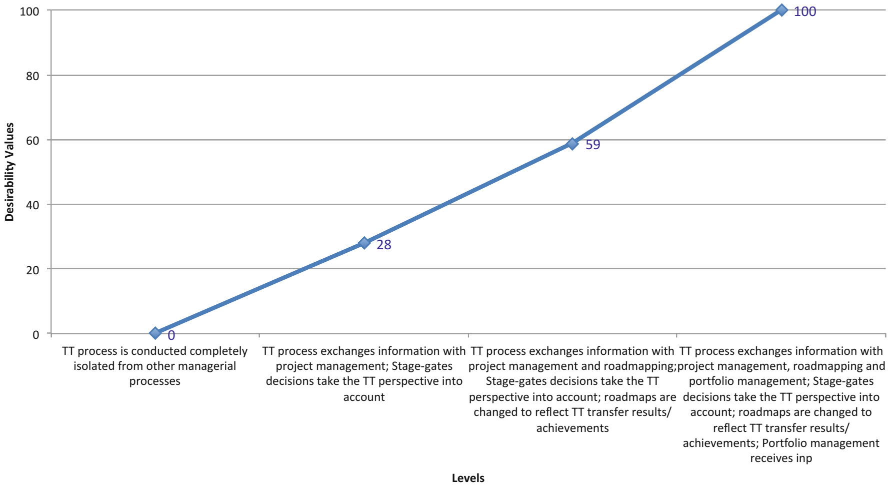

Fig. 19.29 Desirability curve for "Parallel processes integration"

Perspective: HR and Stakeholders

Table 19.40 Desirability metrics quantification results for "TT Team and Training"

TT team and training					
Experts	No dedicated TT team and no training	Dedicated TT team; not multidisciplinary; no training	Dedicated TT team; slightly multidisciplinary (with representatives from more than one department); either no training or informal training	Dedicated TT team; multidisciplinary (with representatives from all relevant departments); formal training	Dedicated TT team; multidisciplinary (with representatives from all relevant departments); formal periodic training (quarterly-based or more often)
E1	0	0	0	27	100
E2	0	25	35	75	100
E3	0	11	23	48	100
E4	0	20	40	85	100
E5	0	10	30	80	100
E6	0	15	30	60	100
E7	0	4	25	51	100
E8	0	19	51	100	100
Mean	0	13	29	66	100

Table 19.41 Desirability metrics quantification results for "TT Ecosystem Mgmt"

TT ecosystem management					
Experts	No interaction with TT ecosystem entities whatsoever	Sparse interaction with TT ecosystem (less than monthly); no cooperation	Frequent interaction (at least monthly); no cooperation	Frequent interaction (at least monthly); formal agreement with some TT ecosystem entities (up to three)	Frequent interaction (at least monthly) and formal agreement with multiple TT ecosystem entities (more than three)
E1	0	4	9	79	100
E2	0	25	49	76	100
E3	0	4	20	55	100
E4	0	10	30	90	100
E5	0	9	40	69	100
E6	0	20	40	80	100
E7	0	7	21	43	100
E8	0	0	19	62	100
Mean	0	10	29	69	100

Table 19.42 Desirability metrics quantification results for "Stakeholders Mgmt"

Stakeholders management					
Experts	TT process is limited to the TT team alone; no one else participates	TT team has sparse contact (less than monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders, but with solicitation)	TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders, but with solicitation)	TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders and without solicitation)	TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes both ways (from and to stakeholders)
E1	0	0	7	48	100
E2	0	24	43	75	100
E3	0	14	27	54	100
E4	0	15	35	45	100
E5	0	20	50	81	100
E6	0	20	0	70	100
E7	0	22	41	65	100
E8	0	19	29	81	100
Mean	0	17	29	65	100

Table 19.43 Desirability metrics quantification results for "Senior Mgmt. Involvement"

Senior management involvement					
Experts	There is no senior management interest in the process	TT process is supported by middle management, but their engagement is not consistent	Middle management is actively engaged in the TT process, but senior management still does not openly support it	Senior management is aware of the TT process, but their engagement is not consistent	There is evidence of consistent engagement and support for the TT process at all levels of the organization
E1	0	0	0	14	100
E2	0	26	50	78	100
E3	0	20	49	71	100
E4	0	25	70	75	100
E5	0	8	17	58	100
E6	0	10	15	50	100
E7	0	10	31	60	100
E8	0	0	8	39	100
Mean	0	12	30	56	100

Perspective: Organizational

Table 19.44 Desirability metrics quantification results for "Communication and Knowledge Mgmt"

Communication and knowledge management				
Experts	Interdepartmental communication is weak; relevant information is not transferred from one department to another without solicitation	Interdepartmental communication is weak; only vital information is transferred from one department to another without solicitation	Interdepartmental communication is strong; relevant information is transferred from one department to another without solicitation	Interdepartmental communication is abundant and intense; knowledge transfer is an inherent behavior in the organization
E1	0	0	20	100
E2	0	25	70	100
E3	0	27	62	100
E4	0	10	60	100
E5	0	5	50	100
E6	0	20	70	100
E7	0	13	46	100
E8	0	8	82	100
Mean	0	14	58	100

Table 19.45 Desirability metrics quantification results for "Funding"

Funding					
Experts	No budget is allocated	1% of R&D budget is allocated to TT activities	Between 1% and 5% of R&D budget is allocated to TT activities	Between 5% and 10% of R&D budget is allocated to TT activities	More than 10% of R&D budget is allocated to TT activities
E1	0	0	0	50	100
E2	0	15	37	52	100
E3	0	23	54	84	100
E4	0	30	50	70	100
E5	0	10	40	100	32
E6	0	20	50	80	100
E7	0	8	28	54	100
E8	0	0	30	100	100
Mean	0	13	36	74	92

Table 19.46 Desirability metrics quantification results for "Absorptive Capacity"

Absorptive capacity					
Experts	The organization does not have steady and successful partnerships, collaborative developments, or joint R&D efforts with external parties	The organization has one steady and successful partnership, collaborative development, or joint R&D effort per year	The organization has between one and three steady and successful partnerships, collaborative developments, or joint R&D efforts per year	The organization has between three and five steady and successful partnerships, collaborative developments, or joint R&D efforts per year	The organization has more than five steady and successful partnerships, collaborative developments, or joint R&D efforts per year
E1	0	0	0	36	100
E2	0	28	49	78	100
E3	0	20	50	75	100
E4	0	40	75	80	100
E5	0	10	29	70	100
E6	0	20	40	60	100
E7	0	28	55	79	100
E8	0	9	19	52	100
Mean	0	19	40	66	100

Table 19.47 Desirability metrics quantification results for "Long-range Planning"

Long-range planning					
Experts	Corporate and business strategies are not propagated	Informal corporate and business strategies are tacitly propagated	Formal corporate and business strategies exist but are tacitly propagated	Formal corporate and business strategies exist and are formally propagated	Formal corporate and business strategies exist, are formally propagated, and employees contrast the strategies against their daily activities
E1	0	0	0	100	0
E2	0	22	48	77	100
E3	0	15	43	78	100
E4	0	20	30	75	100
E5	0	30	43	61	100
E6	0	20	50	90	100
E7	0	16	40	58	100
E8	0	0	19	100	95
Mean	0	15	34	80	87

Perspective: Technical

Table 19.48 Desirability metrics quantification results for "TRL Assessment"

TRL assessment					
Experts	No readiness assessment is conducted for the technologies being developed	Technology readiness is assessed, but does not inform the decision-making process in any ways	Technology readiness is assessed and it informs the decision-making process regarding TT mechanisms and strategies	Readiness assessments are conducted concerning technology (TRL) and system readiness (IRL; SRL); the assessments inform the decision-making process regarding TT mechanisms and strategies	Readiness assessments are conducted concerning technology (TRL), system readiness (IRL; SRL), and R&D degree of difficulty (RD3); the assessments inform the decision-making process regarding TT mechanisms and strategies
E1	0	0	17	33	100
E2	0	28	53	78	100
E3	0	18	40	79	100
E4	0	10	50	80	100
E5	0	4	59	88	100
E6	0	10	50	80	100
E7	0	16	46	64	100
E8	0	0	49	97	100
Mean	0	11	46	75	100

Table 19.49 Desirability metrics quantification results for "Data Management"

Data management					
Experts	Data on technology development is either not collected or collected in informal chats and inquiries	Data is collected in nonstandardized forms; collected data varies from case to case	Data is collected in standardized forms; descriptive data analyses are conducted	Data is collected in standardized forms; descriptive data analyses are conducted; data is stored in an online repository	Data is collected in standardized forms; data is stored in an online repository; descriptive and predictive analyses are made based on current and historical data
E1	0	8	33	60	100
E2	0	18	53	80	100
E3	0	24	53	77	100
E4	0	5	30	80	100
E5	0	15	58	69	100
E6	0	20	60	70	100
E7	0	15	40	61	100
E8	0	9	10	71	100
Mean	0	14	42	71	100

Table 19.50 Desirability metrics quantification results for "Technology Valuation"

Technology valuation					
Experts	No technology assessment studies are conducted throughout the technology development cycle	One technology assessment study is conducted throughout the technology development cycle	Two technology assessment studies are conducted throughout the technology development cycle	Three technology assessment studies are conducted throughout the technology development cycle	More than three technology assessment studies are conducted throughout the technology development cycle
E1	4	19	52	100	100
E2	0	14	48	72	100
E3	0	7	21	75	100
E4	0	5	30	90	100
E5	0	15	30	52	100
E6	0	20	40	60	100
E7	0	13	29	52	100
E8	0	0	19	39	100
Mean	1	12	34	68	100

Table 19.51 Desirability metrics quantification results for "Proposal Assessment"

Proposal assessment					
Experts	Research proposals are not methodically assessed	Research proposals are methodically and qualitatively assessed	Research proposals are methodically and quantitatively assessed	Research proposals are methodically and quantitatively assessed through more than one method	Research proposals are methodically and quantitatively assessed through more than two methods
E1	0	0	16	34	100
E2	0	22	47	83	100
E3	0	10	33	73	100
E4	0	20	30	80	100
E5	0	13	28	60	100
E6	0	30	50	70	100
E7	0	19	42	61	100
E8	0	6	10	76	100
Mean	0	15	32	67	100

Perspective: Process

Table 19.52 Desirability metrics quantification results for "Benefit Management"

Benefit management				
Experts	Project deliverables are seen as benefits	Project deliverables and end products are differentiated	Benefits are classified, quantified, and monitored	Postproject benefit reviews are conducted, and the reviews inform analyses of new proposals
E1	0	9	34	100
E2	0	28	53	100
E3	0	33	69	100
E4	0	10	51	100
E5	0	12	62	100
E6	0	30	60	100
E7	0	9	48	100
E8	9	0	100	83
Mean	1	16	60	98

Table 19.53 Desirability metrics quantification results for "Risk Management"

Risk management				
Experts	The project management perspective of risk is seen as enough	The TT risks and opportunities are identified	The TT risks and opportunities are identified and quantified	The TT risks and opportunities are actively managed; backup plans are devised (risks); follow-on research plan and engagement with external parties are made (opportunities)
E1	0	39	55	100
E2	0	39	70	100
E3	0	27	66	100
E4	0	40	60	100
E5	0	3	49	100
E6	0	30	60	100
E7	0	28	60	100
E8	81	0	92	100
Mean	10	26	64	100

Table 19.54 Desirability metrics quantification results for "Outcomes and Decisions"

Outcomes and decisions					
Experts	No reports are produced and no decisions are made out of the TT process	Nonstandardized reports are produced; recommendations are made based on individual's "gut feeling"	Standardized reports are produced for every project; go–no go decisions are made based on TT data	Project managers and portfolio managers consult with the TT team and use TT data before any major decision	TT team approval is required for every major decision on technology development projects
E1	0	0	16	63	100
E2	0	24	56	80	100
E3	0	22	50	79	100
E4	0	5	60	75	100
E5	0	19	44	90	100
E6	0	20	50	75	100
E7	0	27	56	100	100
E8	0	0	50	100	100
Mean	0	15	48	83	100

Table 19.55 Desirability metrics quantification results for "TT Mechanisms Mgmt"

TT mechanisms management					
Experts	Mechanisms are not identified or planned before the technology is ready	For each project, one TT mechanism is chosen ahead of time and a plan based on the mechanism is devised	For each project, two TT mechanisms are chosen ahead of time and a plan for each mechanism is devised	For each project, three TT mechanisms are chosen ahead of time and a plan for each mechanism is devised	For each project, more than three TT mechanisms are chosen ahead of time and a plan for each mechanism is devised
E1	0	0	63	64	100
E2	0	16	46	70	100
E3	0	14	41	77	100
E4	0	20	40	70	100
E5	0	9	34	64	100
E6	0	30	60	80	100
E7	0	21	48	66	100
E8	0	0	18	51	100
Mean	0	14	44	68	100

Perspective: Strategic Alignment

Table 19.56 Desirability metrics quantification results for "Value, Impact, and Applicability Mgmt"

Value, impact, and applicability management					
Experts	No assessment is made throughout the technology development cycle	One assessment is made at the project start	Two assessments are made at the project start and end	Three assessments are made at the project start, midpoint, and end	More than three assessments are made
E1	0	20	37	50	100
E2	0	23	50	68	100
E3	0	20	45	76	100
E4	0	20	60	95	100
E5	0	8	25	49	100
E6	0	20	50	70	100
E7	0	18	47	69	100
E8	0	0	29	79	100
Mean	0	16	43	70	100

Table 19.57 Desirability metrics quantification results for "Business Plan and Use Case"

Business plan and use case					
Experts	The organization does not create use cases for its technologies	Use cases are available, but they only hve little of the required information	Use cases are available, but they only have some of the required information	Use cases are available and they have most of the required information	Use cases are available and they have all the required information
E1	0	6	66	100	100
E2	0	23	44	70	100
E3	0	20	45	78	100
E4	0	15	20	50	100
E5	0	28	38	66	100
E6	0	24	49	69	100
E7	0	24	49	69	100
E8	0	0	5	82	100
Mean	0	18	40	73	100

Table 19.58 Desirability metrics quantification results for "TT planning, control, and flexibility"

TT planning, control, and flexibility					
Experts	No review and control efforts are made	Annual meetings are conducted to: review the process against strategic management guidelines; set priorities and objectives; identify and reflect on "lessons learned"	Quarterly meetings are conducted to: review the process against strategic management guidelines; set priorities and objectives; identify and reflect on "lessons learned"	Monthly meetings are conducted to: review the process against strategic management guidelines; set priorities and objectives; identify and reflect on "lessons learned"	Weekly meetings are conducted to: review the process against strategic management guidelines; set priorities and objectives; identify and reflect on "lessons learned"
E1	0	51	58	66	100
E2	0	27	56	80	100
E3	0	14	31	82	100
E4	0	25	40	80	100
E5	0	29	49	67	100
E6	0	30	60	90	100
E7	0	26	50	69	100
E8	0	30	50	71	100
Mean	0	29	49	76	100

Table 19.59 Desirability metrics quantification results for "Continuity of TT process"

Continuity of TT process					
Experts	TT process starts after the technology development project is finished	TT process starts at very late stages of the technology development project	TT process starts around the midpoint of the technology development project	TT process starts at very early stages of the technology development project	TT process starts even before the technology development project starts during the proposals and ideas assessment phase
E1	0	6	28	54	100
E2	0	22	40	69	100
E3	0	14	43	69	100
E4	0	10	30	100	60
E5	0	33	51	97	100
E6	0	20	50	80	100
E7	0	26	48	71	100
E8	0	0	50	100	100
Mean	0	16	43	80	95

19.4 Implementation

Having quantified the model and created the desirability curves, the application of the model is conducted using Bonneville Power Administration's Technology Innovation Office as a case.

In order to apply the model to BPA, each factor desirability metric/level was contrasted against the agency's technology transfer process current status with the aim to assign the desirability values. The assignment was done based on the authors' knowledge of the TT process in the agency and also from consultation with some of its managers. After assigning the desirability value of each factor concerning the BPA TT process, the organizational technology transfer score is calculated, thus arriving BPA's TT score.

Following is the desirability values assignment for BPA.

19.4.1 HR and Stakeholders Perspective

- TT team and training.
  - Assigned level: Dedicated TT team; not multidisciplinary; no training.
  - Desirability value: 13.
  - Reasoning: BPA's technology transfer team is comprised by TI Office people only and no technology transfer process training exists.

Table 19.60 Desirability metrics quantification results for "Parallel processes integration"

Parallel processes integration				
Experts	TT process is conducted completely isolated from other managerial processes	TT process exchanges information with project management; stage-gate decisions take the TT perspective into account	TT process exchanges information with project management and roadmapping; stage-gate decisions take the TT perspective into account; roadmaps are changed to reflect TT transfer results/ achievements	TT process exchanges information with project management, roadmapping, and portfolio management; stage-gate decisions take the TT perspective into account; roadmaps are changed to reflect TT transfer results/ achievements; portfolio management receives input from the TT process, aiming for a balanced TT portfolio (in terms of mechanisms, time, and resources)
E1	0	18	39	100
E2	0	19	50	100
E3	0	34	75	100
E4	0	15	40	100
E5	0	19	56	100
E6	0	40	75	100
E7	0	28	61	100
E8	0	50	75	100
Mean	0	28	59	100

- TT ecosystem management.
  - Assigned level: Frequent interactions (at least monthly) and formal agreement with multiple TT ecosystem entities (more than three).
  - Desirability value: 100.
  - Reasoning: BPA funds research conducted by several third parties and maintains close relationships with them, especially national labs and research universities.
- Stakeholders management.

  - Assigned level: TT team has frequent contacts (at least monthly) with internal stakeholders (and external, if any); information goes one way (from the stakeholders, but with solicitation).
  - Desirability value: 29.
  - Reasoning: BPA TT team has frequent contacts with internal stakeholders, both recipients and donors. Information is collected from these stakeholders, but the flow of information is not constant yet, that is, every piece of information collected has to be solicited.

- Senior management involvement.
  - Assigned level: Senior management is aware of the TT process, but their engagement is not consistent.
  - Desirability value: 56.
  - Reasoning: Middle management is consistently supportive and involved in the process development (CTO). Senior managers, in spite of being aware of the efforts, could support, engage in discussions, and participate in a more active way, as to strategically guide the team.

19.4.2 Organizational Perspective

- Communications and knowledge management.
  - Assigned level: Interdepartmental communication is weak. Only vital information is transferred from one department to another without solicitation.
  - Desirability value: 14.
  - Reasoning: The flow of information between groups could and should be better and more intense. Although some progress seems to be happening, this level still best describes the current situation.
- Funding.
  - Assigned level: No budget is allocated.
  - Desirability value: 0.
  - Reasoning: No budget is constantly allocated toward TT activities. Some investments have been made in some instances, but this occurs on a case-by-case basis.
- Absorptive capacity.
  - Assigned level: The organization has more than five steady and successful partnerships, collaborative developments, or joint R&D efforts per year.
  - Desirability value: 100.
  - Reasoning: BPA has several ongoing partnerships with different entities across the United States.
- Long-range planning.

- Assigned level: Formal corporate and business strategies exist, are formally propagated, and employees contrast the strategies against their daily activities.
- Desirability value: 87.
- Reasoning: Although the strategy setting and communication seem to have weakened, this level still best describes the current situation in the agency.

19.4.3 Technical Perspective

- TRL assessment.
  - Assigned level: Technology readiness is assessed, and it informs the decision-making process regarding TT mechanisms and strategies.
  - Desirability value: 46.
  - Reasoning: TRL assessment is conducted and it informs the transfer preparation. For instance, if the final product is at TRL 9, supply chain and procurement processes are initiated; if the final product is at TRL 5, a follow-on research is contemplated. However, no additional measurements are made.
- Data management.
  - Assigned level: Data is collected on standardized forms, and descriptive data analyses are conducted.
  - Desirability value: 42.
  - Reasoning: Standardized forms are in place and are constantly updated to reflect the agency's needs. An online repository is being developed, but is not in place yet.
- Technology valuation.
  - Assigned level: One technology assessment study is conducted throughout the technology development cycle.
  - Desirability value: 12.
  - Reasoning: The only technology assessment-like effort is conducted by ways of analyzing the research proposal, and the information therein explained.
- Proposal assessment.
  - Assigned level: Research proposals are methodically and qualitatively assessed.
  - Desirability value: 15.
  - Reasoning: Research proposals are qualitatively assessed. A quantitative model is being discussed, but has not been implemented yet.

19.4.4 Process Perspective

- Benefit management.
  - Assigned level: Benefits are classified, quantified, and monitored.
  - Desirability value: 60.
  - Reasoning: One of the technology transfer forms' objective is to classify and quantify the expected benefits derived from each project, but these assessments are conducted only as long as the project is still active. There is no postproject effort as of now.
- Risk management.
  - Assigned level: The TT risks and opportunities are identified.
  - Desirability value: 26.
  - Reasoning: TT forms also aim to identify risks and potential opportunities, but no quantification is performed and no backup plans are devised.
- Outcomes and decisions.
  - Assigned level: Nonstandardized reports are produced, and recommendations are made based on individual's "gut feeling".
  - Desirability value: 15.
  - Reasoning: A standardized TT report for each project is being developed, but it is not implemented yet. Go/no go decisions are only made based on the project management dimension.
- TT mechanisms management.
  - Assigned level: For each project, one TT mechanism is chosen ahead of time and a plan based on the mechanism is devised.
  - Desirability value: 14.
  - Reasoning: One and only one TT mechanism is expected per project, and no backup plans are made ahead of time.

19.4.5 Strategic Alignment Perspective

- Value, impact, and applicability management.
  - Assigned level: Three assessments are made: at project start, midpoint, and end.
  - Desirability value: 70.
  - Reasoning: Criteria related to these dimensions are evaluated through the proposal and benefit form (beginning), EV2 (toward the mid-points), and EV3 (toward the end of the project).
- Business plan and use case.

  - Assigned level: Use cases are available, and they have most of the required information.
  - Desirability value: 73.
  - Reasoning: For most of the projects, a clear and comprehensive use case is created to inform stakeholders on how the outcomes are expected to be used.

- TT planning, control, and flexibility.
  - Assigned level: No review and control efforts are made.
  - Desirability value: 0.
  - Reasoning: The process is still being forged and has not been implemented in its entirety. No "process review" meetings are conducted to get feedback from senior managers and strategically improve the process.

- Continuity of TT process.
  - Assigned level: TT process starts even before the technology development project starts during the proposals and ideas assessment phase.
  - Desirability value: 95.
  - Reasoning: TT efforts are conducted before any investments are made, with the benefit form being filled out and analyzed during the proposal evaluation phase.

- Parallel processes integration.
  - Assigned level: TT process exchanges information with project management; stage-gate decisions take the TT perspective into account.
  - Desirability value: 28.
  - Reasoning: The TT process exchanges information with other processes (most importantly project management), but the process outcomes are not actively being used by other processes. Currently, an effort aiming to inform the roadmapping process and update the roadmaps based on the outcomes of the projects and information coming from the TT process is being discussed, but has not been implemented yet.

Table 19.61 summarizes the assignment of values from the desirability curves to BPA's TT process.

The computation of the organizational technology transfer score is done by the application of the formula presented in earlier chapters. Table 19.62 shows the results.

It is evident from the score that BPA is still far from having a completely mature technology transfer process, having scored 40.06 out of 97.75 (41.28% of the total). Moreover, the technical and process perspectives seem to be the least developed in the agency, having contributed with only 5.18 and 5.86 points to the total score, respectively. Analyzing each perspective individually:

- HR and stakeholders.

Table 19.61 Summary of DC values assignment to BPA

Perspective	Factor	Value from DC assigned to BPA
HR and stakeholders	TT team and training	13
	TT ecosystem mgmt	100
	Stakeholders mgmt	29
	Senior mgmt involvement	56
Organizational	Communication and knowledge mgmt	14
	Funding	0
	Absorptive capacity	100
	Long-range planning	87
Technical	TRL assessment	46
	Data mgmt	42
	Technology valuation	12
	Proposal assessment	15
Process	Benefit mgmt	60
	Risk mgmt	26
	Outcomes and decisions	15
	TT mechanisms mgmt	14
Strategic alignment	Value, impact, and applicability mgmt	70
	Business plan and use case	73
	TT planning, control, and flexibility	0
	Continuity of TT process	95
	Parallel processes integration	28

  - "TT team and training" is the most underperforming factor under this perspective and should be tackled first.
- Organizational.
  - "Funding" and "Communication and knowledge management" are the most underperforming factors under this perspective and should be tackled first.
- Technical.
  - "Technology valuation" and "Proposal assessment" are the most underperforming factors under this perspective and should be tackled first.
- Process.
  - "Outcomes and decisions" and "TT mechanisms management" are the most underperforming factors under this perspective and should be tackled first.
- Strategic alignment.
  - "TT planning, control, and flexibility" and "Parallel processes integration" are the most underperforming factors under this perspective and should be tackled first.

Table 19.62 BPA's organizational TT score

Perspectives	Factors		TT score		
	Name	Global values	BPA values	Values × factors	Perspective sum
HR and stakeholders	TT team and training	0.06	13	0.78	9.59
	TT ecosystem mgmt	0.04	100	4	
	Stakeholders mgmt	0.05	29	1.45	
	Senior mgmt involvement	0.06	56	3.36	
Organizational	Communication and knowledge mgmt	0.06	14	0.84	9.32
	Funding	0.06	0	0	
	Absorptive capacity	0.05	100	5	
	Long-range planning	0.04	87	3.48	
Technical	TRL assessment	0.05	46	2.3	5.18
	Data mgmt	0.04	42	1.68	
	Technology valuation	0.05	12	0.6	
	Proposal assessment	0.04	15	0.6	
Process	Benefit mgmt	0.05	60	3	5.86
	Risk mgmt	0.06	26	1.56	
	Outcomes and decisions	0.04	15	0.6	
	TT mechanisms mgmt	0.05	14	0.7	
Strategic alignment	Value, impact and applicability mgmt	0.05	70	3.5	10.11
	Business plan and use case	0.04	73	2.92	
	TT planning, control, and flexibility	0.04	0	0	
	Continuity of TT process	0.03	95	2.85	
	Parallel processes integration	0.03	28	0.84	
Total sum					40.06

19.4.6 Sensitivity Analysis

After finishing the organizational technology transfer score for the Technology Innovation group at BPA, a sensitivity analysis is conducted to test the robustness of the model. This analysis aims to measure how the model's final output will react to changes in the relevance of criteria. In a model with different technology alternatives, for instance, the final ranking of the alternatives might be altered if the criteria relevance is altered, and the sensitivity analysis would measure how strong or disruptive these changes would be. Bringing the same reasoning to this model, the sensitivity analysis will indicate the changes in the final organizational TT score caused by alterations in the perspective relevance. This could be particularly interesting if one is to use this model to compare different departments within an organization or to compare different organizations. Moreover, when applying the model to only one case, changing the weights of the perspectives could prompt the technology manager to change his/her reasoning when prioritizing the factors to be tackled. For example, if the technical perspective is, by far, the most relevant, weak factors under the technical perspective should be prioritized, even if the organization seems to be performing better in those factors relative to factors under other perspectives. Following sensitivity analyses made by Abotah and Estep [1, 18], different scenarios were created. Each scenario alters the relevance of perspectives by boosting one of the perspectives. For example, in scenario one, the perspective "HR and stakeholders" has its relevance boosted to 0.96, while the remaining perspectives have theirs at 0.01 each, and so on. Tables 19.63, 19.64, 19.65, 19.66, 19.67 show the results of the five scenarios created.

As expected, changing the perspective relevance incurs changes in the organizational TT score. In the case of BPA, the score hits its lowest level when the perspectives "Technical" or "Process" have their importance maximized (these are the worst-performing perspectives of the agency, according to the model application). Conversely, the score hits its highest level when the perspective "Strategic alignment" has its importance maximized (this is the best-performing perspective of the agency, according to the model application). Table 19.68 brings a summary of the sensitivity analysis results.

As previously indicated, these changes could inform managers on how to proceed about their efforts toward improving their technology transfer capabilities.

19.5 Conclusions, Limitations, and Future Research

This chapter had as its objective the development and application of a model to measure an organization's technology transfer capabilities. This was accomplished by means of building a hierarchical model using action research and hierarchical decision modeling as a methodology and applying the model to a power utility company in the Northwest region of the United States. Overall, the contributions of this study can be divided into two. On the theoretical side, a new approach to tackling technology transfer issues has been presented, using hierarchical decision modeling aided by action research and also feeding back the technology transfer theory with insights from the action research project that served as a basis for building the hierarchical model. On the practical side, technology managers now have an intuitive tool to apply in their organizations and perceive benefits from it, both in terms of having a higher awareness of where their technology transfer

Table 19.63 Sensitivity analysis—scenario 1 results

Scenario 1—HR and stakeholders boosted to 0.96							
Perspectives		Factors			TT score		
Name	Value	Name	Local value	Global value	BPA values	Values × factors	Perspective sum
HR and stakeholders	0.96	TT team and training	0.27	0.259	13	3.37	44.04
		TT ecosystem mgmt	0.20	0.192	100	19.20	
		Stakeholders mgmt	0.25	0.240	29	6.96	
		Senior mgmt involvement	0.27	0.259	56	14.52	
Organizational	0.01	Communication and knowledge mgmt	0.28	0.003	14	0.04	0.44
		Funding	0.29	0.003	0	0.00	
		Absorptive capacity	0.23	0.002	100	0.23	
		Long-range planning	0.20	0.002	87	0.17	
Technical	0.01	TRL assessment	0.29	0.003	46	0.13	0.29
		Data mgmt	0.23	0.002	42	0.10	
		Technology valuation	0.26	0.003	12	0.03	
		Proposal assessment	0.22	0.002	15	0.03	
Process	0.01	Benefit mgmt	0.25	0.003	60	0.15	0.29
		Risk mgmt	0.28	0.003	26	0.07	
		Outcomes and decisions	0.22	0.002	15	0.03	
		TT mechanisms mgmt	0.24	0.002	14	0.03	
Strategic alignment	0.01	Value, impact, and applicability mgmt	0.26	0.003	70	0.18	0.54
		Business plan and use case	0.20	0.002	73	0.15	
		TT planning, control, and flexibility	0.21	0.002	0	0.00	
		Continuity of TT process	0.17	0.002	95	0.16	
		Parallel processes integration	0.17	0.002	28	0.05	
Total sum							45.61

Table 19.64 Sensitivity analysis—scenario 2 results

Scenario 2—Organizational boosted to 0.96							
Perspectives		Factors			TT score		
Name	Value	Name	Local value	Global value	BP values	Values × factors	Perspective sum
HR and stakeholders	0.01	TT team and training	0.27	0.003	13	0.04	0.46
		TT ecosystem mgmt	0.20	0.002	100	0.20	
		Stakeholders mgmt	0.25	0.003	29	0.07	
		Senior mgmt involvement	0.27	0.003	56	0.15	
Organizational	0.96	Communication and knowledge mgmt	0.28	0.269	14	3.76	42.55
		Funding	0.29	0.278	0	0.00	
		Absorptive capacity	0.23	0.221	100	22.08	
		Long-range planning	0.20	0.192	87	16.70	
Technical	0.01	TRL assessment	0.29	0.003	46	0.13	0.29
		Data mgmt	0.23	0.002	42	0.10	
		Technology valuation	0.26	0.003	12	0.03	
		Proposal assessment	0.22	0.002	15	0.03	
Process	0.01	Benefit mgmt	0.25	0.003	60	0.15	0.29
		Risk mgmt	0.28	0.003	26	0.07	
		Outcomes and decisions	0.22	0.002	15	0.03	
		TT mechanisms mgmt	0.24	0.002	14	0.03	
Strategic alignment	0.01	Value, impact, and applicability mgmt	0.26	0.003	70	0.18	0.54
		Business plan and use case	0.20	0.002	73	0.15	
		TT planning, control, and flexibility	0.21	0.002	0	0.00	
		Continuity of TT process	0.17	0.002	95	0.16	
		Parallel processes integration	0.17	0.002	28	0.05	
Total sum							44.13

Table 19.65 Sensitivity analysis—scenario 3 results

Scenario 3—Technical boosted to 0.96							
Perspectives		Factors			TT score		
Name	Value	Name	Local value	Global value	BPA values	Values × factors	Perspective sum
HR and stakeholders	0.01	TT team and training	0.27	0.003	13	0.04	0.46
		TT ecosystem mgmt	0.20	0.002	100	0.20	
		Stakeholders mgmt	0.25	0.003	29	0.07	
		Senior mgmt involvement	0.27	0.003	56	0.15	
Organizational	0.01	Communication and knowledge mgmt	0.28	0.003	14	0.04	0.44
		Funding	0.29	0.003	0	0.00	
		Absorptive capacity	0.23	0.002	100	0.23	
		Long-range planning	0.20	0.002	87	0.17	
Technical	0.96	TRL assessment	0.29	0.278	46	12.81	28.24
		Data mgmt	0.23	0.221	42	9.27	
		Technology valuation	0.26	0.250	12	3.00	
		Proposal assessment	0.22	0.211	15	3.17	
Process	0.01	Benefit mgmt	0.25	0.003	60	0.15	0.29
		Risk mgmt	0.28	0.003	26	0.07	
		Outcomes and decisions	0.22	0.002	15	0.03	
		TT mechanisms mgmt	0.24	0.002	14	0.03	
Strategic alignment	0.01	Value, impact, and applicability mgmt	0.26	0.003	70	0.18	0.54
		Business plan and use case	0.20	0.002	73	0.15	
		TT planning, control, and flexibility	0.21	0.002	0	0.00	
		Continuity of TT process	0.17	0.002	95	0.16	
		Parallel processes integration	0.17	0.002	28	0.05	
Total sum							29.97

Table 19.66 Sensitivity analysis—scenario 4 results

Scenario 4—Process boosted to 0.96							
Perspectives		Factors			TT score		
Name	Value	Name	Local value	Global value	BPA values	Values × factors	Perspective sum
HR and stakeholders	0.01	TT team and training	0.27	0.003	13	0.04	0.46
		TT ecosystem mgmt	0.20	0.002	100	0.20	
		Stakeholders mgmt	0.25	0.003	29	0.07	
		Senior mgmt involvement	0.27	0.003	56	0.15	
Organizational	0.01	Communication and knowledge mgmt	0.28	0.003	14	0.04	0.44
		Funding	0.29	0.003	0	0.00	
		Absorptive capacity	0.23	0.002	100	0.23	
		Long-range planning	0.20	0.002	87	0.17	
Technical	0.01	TRL assessment	0.29	0.003	46	0.13	0.29
		Data mgmt	0.23	0.002	42	0.10	
		Technology valuation	0.26	0.003	12	0.03	
		Proposal assessment	0.22	0.002	15	0.03	
Process	0.96	Benefit mgmt	0.25	0.240	60	14.40	27.78
		Risk mgmt	0.28	0.269	26	6.99	
		Outcomes and decisions	0.22	0.211	15	3.17	
		TT mechanisms mgmt	0.24	0.230	14	3.23	
Strategic alignment	0.01	Value, impact, and applicability mgmt	0.26	0.003	70	0.18	0.54
		Business plan and use case	0.20	0.002	73	0.15	
		TT planning, control, and flexibility	0.21	0.002	0	0.00	
		Continuity of TT process	0.17	0.002	95	0.16	
		Parallel processes integration	0.17	0.002	28	0.05	
Total sum							29.52

Table 19.67 Sensitivity analysis—scenario 5 results

Scenario 5—Strategic alignment boosted to 0.96							
Perspectives		Factors			TT score		
Name	Value	Name	Local value	Global value	BPA values	Values × factors	Perspective sum
HR and stakeholders	0.01	TT team and training	0.27	0.003	13	0.04	0.46
		TT ecosystem mgmt	0.20	0.002	100	0.20	
		Stakeholders mgmt	0.25	0.003	29	0.07	
		Senior mgmt involvement	0.27	0.003	56	0.15	
Organizational	0.01	Communication and knowledge mgmt	0.28	0.003	14	0.04	0.44
		Funding	0.29	0.003	0	0.00	
		Absorptive capacity	0.23	0.002	100	0.23	
		Long-range planning	0.20	0.002	87	0.17	
Technical	0.01	TRL assessment	0.29	0.003	46	0.13	0.29
		Data mgmt	0.23	0.002	42	0.10	
		Technology valuation	0.26	0.003	12	0.03	
		Proposal assessment	0.22	0.002	15	0.03	
Process	0.01	Benefit mgmt	0.25	0.003	60	0.15	0.29
		Risk mgmt	0.28	0.003	26	0.07	
		Outcomes and decisions	0.22	0.002	15	0.03	
		TT mechanisms mgmt	0.24	0.002	14	0.03	
Strategic alignment	0.96	Value, impact, and applicability mgmt	0.26	0.250	70	17.47	51.56
		Business plan and use case	0.20	0.192	73	14.02	
		TT planning, control, and flexibility	0.21	0.202	0	0.00	
		Continuity of TT process	0.17	0.163	95	15.50	
		Parallel processes integration	0.17	0.163	28	4.57	
Total sum							53.05

Table 19.68 Sensitivity analysis results summary

Scenario	Boosted perspective	Org TT score	Score rank
Original	None	40.06	4th
1	HR and stakeholders	45.61	2nd
2	Organizational	44.13	3rd
3	Technical	29.97	5th
4	Process	29.52	6th
5	Strategic alignment	53.05	1st

processes and initiatives stand, and also in terms of identifying strong and weak points in their processes, aiding the development of an action plan to improve their technology transfer capabilities.

In terms of methodological limitations, the model heavily relies on the judgments of subject matter experts, with all their biases, making the subjectivity one of the biggest limitations, along with potential logical inconsistencies and disagreements between experts. Also, as shown by the sensitivity analysis, changes in the weights or importance of the criteria could have as a consequence changes in the final results, making the generalizability another limitation (in order to apply the model to other circumstances, such as different times and different industries, it would be more appropriate to review the model components, seeking to revalidate and redo the quantification according to the new circumstances). Moreover, as much as the application of the model indicates where to start in terms of improving the organization's technology transfer capabilities, it does not give any specific guidelines on how to conduct those improvements.

Taking into account the limitations discussed above, it is possible to identify opportunities for future research, with the aim to enhance the model and to address some of these limitations. First, in terms of applicability and generalizability, the model could be applied to more cases, and the usability and usefulness of the tool should be discussed with practitioners looking to improve the tool. Also, the model should be applied to different industry sectors with special attention to the necessity (or not) to review, update, and adapt the model components accordingly, in order to check how generalizable it is. In terms of advancing the benefits obtained out of the model application, further research should be conducted on the determination of a technology transfer maturity scale, having the maturity level definitions in consonance with the model components. In addition, further investigation and interviews with practitioners could enable the creation of guidelines and templates of action plans to address the weaknesses identified by the model, without hindering the strengths, thereby extending the model application into actual positive actions toward improving an organization's technology transfer capabilities.

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Chapter 20
Technology Licensing Performance and Strategy of US Research Institutions

Jisun Kim, Tuğrul Daim, and João Ricardo Lavoie

20.1 Background

This paper builds upon Kim and Daim [1] to implement a model to evaluate university technology commercialization. Kim and Daim [1] developed a scheme to calculate the time lags between inputs into the university research and licensing outputs resulting from this research. This study uses that scheme to calculate the time lags, then goes on and leverages Malmquist index approach to calculate efficiency of university technology licensing and finally identifies the factors impacting this efficiency. Much of the literature has been reviewed in the prior publications and a summary is presented in Table 20.1.

20.2 Research Framework

The present study assesses the relative licensing productivity of academic research institutions. The results will indicate how well a particular institution is licensing its technology, given its resources, relative to other universities. For this purpose, this study develops a research process as below:

Prior versions of this study were presented at PICMET conferences.

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Innovation, Technology, and Knowledge Management,
https://doi.org/10.1007/978-3-030-15409-7_20

Table 20.1 Literature review summary

Topic/characteristic	Literature
Development state of discovery	
University missions and goals	Ponomariov [2], Nelson [3], Audretsch and Lehmann [4], Chapple et al. [5], Markman et al. [6], Wong et al. [7], Woolgar [8], Djokovic and Souitaris [9], Gopalakrishnan and Santoro [10]
Institutions' private or public status	Abbott [11], Powers [12], Lach and Schankerman [13], Thursby and Kemp [14], Siegel et al. [15], Anderson et al. [16], Markman et al. [17]
The existence of medical school	Baldini et al. [18], Powers [12], Chapple et al. [5], Siegel et al. [15], Anderson et al. [16]
Academic prestige	Rasmussen et al. [19]
University size (budget)	Baldini et al. [18]
Technology licensing office	Rasmussen et al. [19], Macho-Stadler et al. [20], Siegel et al. [15], Markman et al. [6], Sharma et al. [21], Vaidyanathan [22]
TLO size	Powers [12], Markman et al. [17], Lach and Schankerman [13], Baldini et al. [18]
TLO age	Lach and Schankerman [13], Siegel et al. [15], Powers [12], Markman et al. [17], Chapple et al. [5]
TLO structure	Markman et al. [6], Siegel et al. [23], Kodama [24], Gulbranson and Audretsch [25], Acworth [26]
Nonexclusive licensing policy	Kapczynski et al. [27]
Exclusive licensing policy	Kapczynski et al. [27]
Licensing for cash	Trune and Goslin [28], Markman et al. [6], Welsh et al. [29]
Licensing for equity	Markman et al. [6]
Licensing for sponsored research	Markman et al. [6]
Faculties' relationship with industry	Ponomariov [2], Siegel et al. [30], Siegel et al. [23], Martinelli et al. [31]
Faculty quality	Salter and Martin [32], Hicks et al. [33], Powers [12]
TLO's personnel skills	Yusuf [34], Gulbranson and Audretsch [25], Bramwell and Wolfe [35], Chapple et al. [5], Siegel et al. [15], Colyvas et al. [36]
Federal R&D support	Powers [12], Boardman and Ponomariov [37]
Industry R&D support	Powers [12]
Regional GDP	Chapple et al. [5]

- First, the process of ARITC and its input and output structure are defined through a literature review. The characteristics influencing the performance of ARITC are identified.
- Second, time-lag coefficients are identified through a suggested time-lag identifying process in order to incorporate into the ARITC efficiency model the duration between input and output variables.

- Third, the relative efficiencies of the ARITC are evaluated. The modified super-efficiency Banker, Charnes, and Cooper (BCC) [38] DEA model is suggested to assess the technology licensing efficiencies of U.S. academic research institutions from 1991 to 2007. Infeasibility and computation limitation due to zero data of the DEA model are discussed and a solution is provided. Time lag effect neutralized data are used for the analysis. In addition to the efficiency scores in each year, efficiency changes during the studied year are measured using Malmquist Index.
- Finally, the relationships among characteristics and efficiencies and their changes are examined to define characteristic patterns and to understand the technology licensing practices of the observed institutions.

20.3 Methods

20.3.1 A New Process for Identifying Time-Lag Coefficients in Licensing

Time lags among the licensing data are examined by using a distributed lag regression model. The distributed regression model, a well-known and widely used time series analysis in economics, estimates causal effects on two subjects. For this purpose, a series of statistical processes have been developed. The five steps for identifying time-lag coefficients are presented in Fig. 20.1.

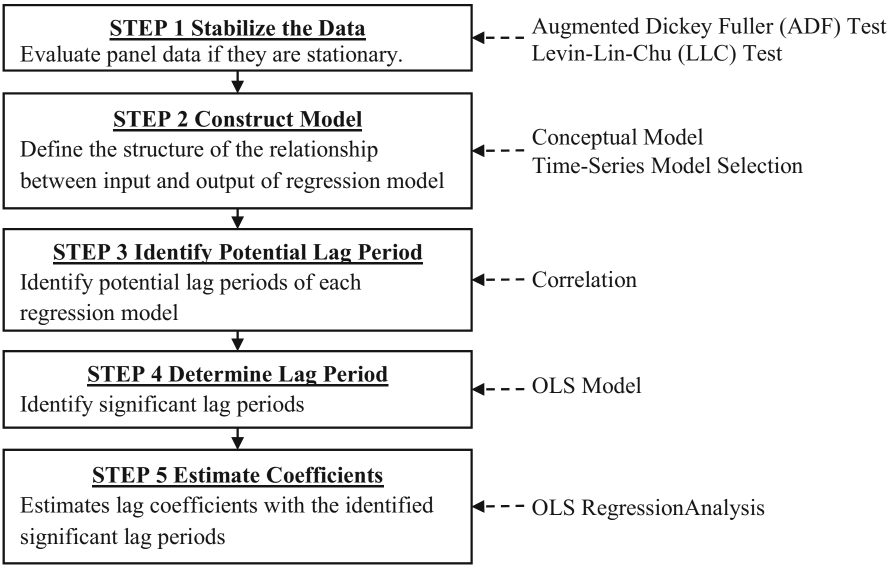

Fig. 20.1 Process to identify time-lag distribution coefficients [1]

20.3.2 Output-Oriented Super-Efficiency DEA Model

Lovell and Rouse [39], Cook et al. [40], and Lee et al. [41] attempted to provide an output oriented super-efficiency DEA model to resolve a computational infeasibility problem. Although each method provides unique benefits in finding the super-efficiency scores, none of them is applicable if zero values are associated with the data. The licensing of the U.S. academic research institution technologies in the early 1990s was not active, and there were several institutions that didn't have experience with start-up companies. If these data are applied to any of the super-efficiency models, it will result in infeasibility or zero-efficiency scores. Therefore, this study employs a three-stage DEA model (Fig. 20.2) that allows zero values in data and resolves the general infeasibility issue by adopting the nonradial model (Russell measure) of Färe and Lovell [42] and the modified super-efficiency model of Lee et al. [41].

STAGE 1

Identify potential input saving ($t_i x_i^k$)

$$\begin{aligned} &\text{Min } \textstyle\sum_{i=1}^{m} t_i \\ &\text{s.t. } \textstyle\sum_{\substack{j=1\\ j\neq k}}^{n} \lambda_j x_i^j - t_i x_i^k \le x_i^k \qquad i=1,2,\ldots,m \\ &\textstyle\sum_{\substack{j=1\\ j\neq k}}^{n} \lambda_j = 1 \\ &\lambda_j \ge 0,\ j \neq k \\ &t_i \ge 0,\ i=1,2,\ldots,M \end{aligned}$$

$t_i x_i^k > 0$ if a DMU is super efficeient, otherwise zero

STAGE 2

Evaluate non-radial efficiency

$$\begin{aligned} &\text{Max } \tfrac{1}{m}\textstyle\sum_{i=1}^{m} \widehat{\beta}_r \\ &\text{s.t. } \textstyle\sum_{\substack{j=1\\ j\neq k}}^{n} \lambda_j x_i^j - t_i^* x_i^k \le x_i^k \qquad i=1,2,\ldots,m \\ &\textstyle\sum_{\substack{j=1\\ j\neq k}}^{n} \lambda_j y_r^j \ge \widehat{\beta}_r y_r^k \qquad r=1,2,\ldots,s \\ &\textstyle\sum_{\substack{j=1\\ j\neq k}}^{n} \lambda_j = 1 \\ &\lambda_j \ge 0,\ j \neq k \end{aligned}$$

Non-radial efficient $\widehat{\beta}_r$ for each output r

STAGE 3

Define modified super efficiency

$$\frac{1}{\breve{\beta}} = \begin{cases} \dfrac{\sum_{i\in I}\left(\dfrac{x_i^k + t_i^* x_i^k}{x_i^k}\right)}{|I|} + \dfrac{1}{\widehat{\beta}^*}, & \text{if } I \neq \phi \\ \dfrac{1}{\widehat{\beta}^*}, & \text{if } I = \phi \end{cases}$$

Where $I = \{i \mid t_i^* > 0\}$ and $\widehat{\beta}^* = \frac{1}{m}\sum_{i=1}^{m} \widehat{\beta}_r^*$

If an input savings exists for an evaluated DMU, add average of the savings to the efficiency.

Fig. 20.2 A new three-stage data envelopment analysis model

20.3.3 Malmquist Index

The Malmquist Index measures the difference in the relative distances of a DMU from time t to t + 1. The index tells us how the technology changes over time. The Malmquist decompositions can explain in detail whether the change is due to the efficiency change or to technical change. The traditional Malmquist Index was suggested by Caves et al. [43] and Färe et al. [44], who further developed it to incorporate a variable returns to scale, which became the widely used Malmquist Index. The two decompositions of the Malmquist Index by Färe et al. are applied to this study (see the appendix for the Malmquist Index Model).

20.3.4 Data

The time-lag analysis employed data from the Association of University Technology Managers licensing survey of U.S. academic research institutions from 1991 to 2007. Raw data on about 198 institutions was reviewed and refined before being used for the analysis. The remaining 46 institutions used in the analysis are listed in Table 20.2. The licensing variables studied include disclosure, patent applications, patents issued, licenses and options executed, start-ups, and licensing income. Data of organization characteristics such as institution types, academic rankings, and TLO's FTEs are collected from various resources, including US News Ranking, National Center for Education Statistics (NCES), AUTM, and institutions' websites.

20.4 Licensing Time Lags in 46 U.S. Academic Research Institutions

The time lag identifying process, using a distributed lag model with an unstructured coefficient structure, was applied to the data from 46 U.S. academic research institutions. A total of 21 regression models were applied to each step, and they successfully identified the time-lag effect between each pair of the seven licensing variables, including research expenditure, disclosure, patent application, patents issued, licenses and options executed, start-up, and licensing income. The AUTM licensing survey data of the 46 institutions from 1991 to 2007 was used for the analysis. For instance, the lag coefficients of expenditure to disclosure are estimated using the model with lag 0, 1, and 5.

$$\Delta y_{i,t}^{\mathrm{DIS}} = \beta_0 \Delta x_{i,t}^{\mathrm{EXP}} + \beta_1 \Delta x_{i,t-1}^{\mathrm{EXP}} + \beta_5 \Delta x_{i,t-5}^{\mathrm{EXP}} + e_t \tag{20.1}$$

Table 20.2 The 46 institutions used for the time-lag analysis

Ranking (Income, 2007)	Academic institutions	Ranking (Income, 2007)	Academic institutions
1	City of Hope National Medic	24	Univ. of Oregon
2	Northwestern Univ.	25	Indiana Univ. (ARTI)
3	Wake Forest Univ.	26	Ohio Univ.
4	Univ. of Minnesota	27	Fred Hutchinson Cancer Res.
5	Massachusetts Inst. of Tech.	28	Clemson Univ.
6	Mayo Foundation	29	Univ. of Southern California
7	Univ. of Utah	30	Dartmouth College
8	Univ. of Iowa Research Fdn.	31	St. Jude Children's Res.
9	Univ. of Michigan	32	Brigham Young Univ.
10	Harvard Univ.	33	Colorado State Univ.
11	Washington Univ.	34	Oregon State Univ.
12	Case Western Reserve Univ.	35	Georgia Inst. of Technology
13	Baylor College of Medicine	36	Penn State Univ.
14	Johns Hopkins Univ.	37	Florida State Univ.
15	California Institute of Tech.	38	Ohio State Univ.
16	Vanderbilt Univ.	39	Univ. of Arizona
17	Brigham & Women's Hospital, Inc.	40	Univ. of Maryland, College
18	Rutgers, The State Univ.	41	Univ. of Connecticut
19	Univ. of Texas Southwestern	42	Univ. of Cincinnati
20	Tulane Univ.	43	Univ. of Delaware
21	Univ. of Akron	44	New Jersey Institute of Tech.
22	Michigan State Univ.	45	National Jewish Center
23	Univ. of Virginia Patent Fdn.	46	Univ. of Dayton

All of the coefficients are significant and have a value of 1.78 for lag 0, 1.67 for lag1, and 1.49 for lag 5. If these coefficient values are normalized, the percentage of expenditure at a certain year relative to the disclosure at year *t* can be found. In this case, the 36% of expenditure at year *t*, 34% at *t*–1, and 30% at *t*–5 are associated with the number of disclosures at *t*.

The standardized time-lag coefficients, along with the licensing process, are illustrated in Fig. 20.3. The shortest time lag in the licensing process, if the durations are added up, is 2 years, and the longest one is 27 years. The time-lag model between

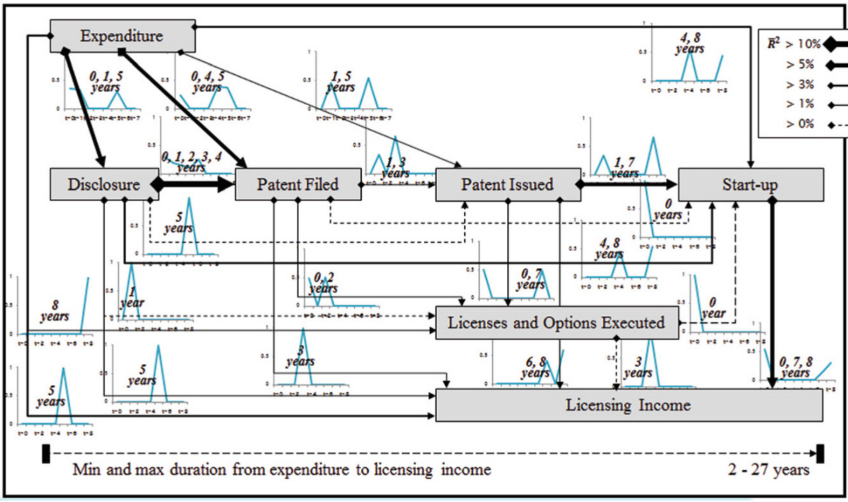

Fig. 20.3 Licensing process with the time-lag coefficients

disclosure and patent filed has the greatest explanatory power ($R^2 = 0.1$) among the 21 regression models, though all of the models have very low R^2 values. However, because the purpose of the regression models is to identify significant time-lag coefficients rather than to explain a dependent variable by independent variables, the R^2 values of the regression models are not seriously considered.

The minimum duration from expenditures to licensing is 2 years and the maximum is 27 years. Although the model identified the continuous time-lag effect of 4 years from disclosure to patent filed, it detected discontinuous lag periods ranging from 1 year to 3 years. This reflects the institutions' licensing practices. After inventions are disclosed through the licensing offices, most of them are filed, thus producing significant distribution across the periods up to 4 years. On the other hand, the lag relationships between a posterior (output) and prior (input) licensing variable depend on the quality and attractiveness of the prior variable in licensing. Therefore, more uncertainty and greater variations of time-lag effects exist in those variables.

20.5 Licensing Performance and Influencing Characteristics

20.5.1 Licensing Performance

The licensing or commercialization performance of 46 U.S. research institutions was explored using modified super-efficiency models and the Malmquist Index. The time-lag effect neutralized data for the input of research expenditure from 1991 to

1999 and the outputs of patent applications, start-ups, and licensing income from 1992 to 2007 were used for the analysis. The super-efficiency scores of the 11 super-efficient or extremely super-efficient best practicing institutions during the period are summarized in Table 20.3.

Brigham Young University and the Massachusetts Institute of Technology are identified as super-efficient universities for all the years. The California Institute of Technology and the University of Akron were super-efficient for most of the years studied, whereas Dartmouth College was efficient only in 1995. Ohio University was efficient in 1991 and 1992, and inefficient since then. On the other hand, three universities became efficient in 1998 or 1999.

All of the institutions show improved performance (MI $>$ 1) during the period (See appendix for the averages of universities' scores during the periods studied). All of the institutions also experienced frontier expansion (TC $>$ 1) during the period, which means that all other best practicing institutions improved their performance. Also, all but eight institutions improved efficiency (EC $>$ 1) over the same time period. The efficiency change of an evaluated DMU tends to decline if the frontier of the DMU is expanding (TC $>$ 1) in the following year compared to an identical frontier, because the distance between the DMU and frontier becomes larger. Given this, the improved efficiency is significant. This also indicates that performance improvements existed throughout all institutions.

Table 20.3 Modified super-efficiency scores of 11 institutions (1991–1999)

	Modified super-efficiency scores; Dt(t)								
Institutions	1991	1992	1993	1994	1995	1996	1997	1998	1999
Brigham Young Univ.	2.09	1.16	17.66	3.25	1.25	1.93	2.22	2.05	1.88
California Institute of Tech.		1.52	1.57	1.13	1.25	1.67	2.36	2.73	3.15
City of Hope National Medic	5.17	2.47	1.74			1.06	1.75	3.16	1.68
Dartmouth College					1.59				
Florida State Univ.			1.41	2.43	1.02	1.94	1.33		
Massachusetts Inst. of Tech	3.33	2.79	2.34	2.35	2.21	2.59	1.86	2.03	2.04
Ohio Univ.	3.01[a]	5.11							
Univ. of Akron	2.11		1.47	3.04	4.78	4.07[a]	4.26	2.95	4.76
Univ. of Minnesota									1.08
Univ. of Utah								1.07	1.19
Wake Forest Univ.									1.01

[a]Average of nonradial output super-efficiency scores are applied

20.5.2 Influencing Instructional Characteristics to the Licensing Performance

The six licensing outcome variables were regressed to expenditure and characteristics variables, including journal articles, average rankings (higher is better), private status, and presence of a medical school. The second model includes TLO variables such as TLO age, licensing FTEs in TLOs, and other FTEs in TLOs (Table 20.4). Private or public status and existence of a medical school were not significant throughout all models. The journal articles were positively related to disclosure and start-up. The average ranking of an institution was related only to number of patents issued. More licensing FTEs were related to more licenses and options executed. On the other hand, older TLOs were related to more start-ups.

The average efficiency and Malmquist Index scores were regressed to the characteristic variables (Tables 20.5 and 20.7). The existence of a medical school had a negative effect on average efficiency. TLO licensing-related FTE per expenditure was positively related to both efficiency and efficiency change. Other FTE per expenditure was related to higher efficiency. Private institutions showed positive effects on average efficiency change.

20.6 Discussion

20.6.1 Licensing Time Lags

The individual time-lag relationships between two licensing variables are extended to multipath lag effects on licensing income as a final result of licensing activities. The average lag from expenditure to licensing income throughout all possible paths is 10.3 years, and the most plausible lags, which have higher standard lag coefficient values, are 5 (9%) and 8 (10%) years. The overall lags range from 0 to 27 years. Time lags between disclosure and licensing income range from zero to 22 years, with an average of 8.8 years. The time lag periods, which have the highest effect from the disclosure to licensing income are 4 (12%) and 5 (11%) years.

Patent applications and patents issued have similar average lags—6.7 and 7.3 years, respectively. Licenses and options executed and start-up also have similar average lag periods—3.3 and 3.5 years, respectively. The average lags of the two licensing activities are smaller than any other lags. This is a reasonable result because these two variables represent actual licensing practice, which has a high correlation to licensing income.

Interesting observations can be made when the two time lags of the highest aggregated coefficients are selected for each licensing variable. Although disclosure and patents issued have consecutive lags, two time lags of all others are far from each other. This might reflect different licensing paths among them.

Table 20.4 Regression of licensing outcomes to characteristic variables (four institution types excluded)

	Cumulative licensing outcomes										
	Disclosure		Patent applications		Patents issued		Licenses and options executed		Start-ups		Licensing income
Variables	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1&2
Expenditure	0.65**	0.40**	0.82**	0.71**	0.66**	0.41**	0.71**	0.38**	0.46**	0.19	–
Journal articles	0.26*	0.22	0.13	0.10	0.21	0.15	0.13	0.10	0.36**	0.26*	–
Average ranking	0.13	0.05	0.05	0.01	0.24*	0.16	0.10	0.00	0.31*	0.20	–
Private status	0.11	0.10	0.10	0.09	0.10	0.09	0.15	0.17	0.07	0.03	–
Medical school	−0.08	−0.16	−0.15	−0.17	−0.08	−0.14	0.06	−0.06	−0.12	−0.17	–
Technology licensing office age		0.18		0.14		0.23		0.08		0.43**	–
Licensing full-time equivalents in technology licensing office		0.23		0.02		0.14		0.32**		0.14	–
Other full-time equivalents in technology licensing offices		0.12		0.05		0.14		0.26		0.05	–
Adjusted R^2	0.56**	0.72**	0.69**	0.74**	0.60**	0.68**	0.62**	0.79**	0.48**	0.67**	–

*p-value <0.1, **p-value <0.05

Table 20.5 Regression of efficiency and efficiency changes to characteristic variables (four institution types)

Independent variables	Dependent variable	
	Average efficiency	Average Malmquist index
Total Number of Journal Articles from 1991 to 2007	0.13	0.04
Average of Hospital, Medical, Science, and Engineering Ranking	−0.12	−0.11
Private or public status	0.21	0.27*
Existence of a Medical School	−0.34**	−0.18
Universities	0.42	0.36
Medical Research Centers	0.30	0.07
Special-Focus Institutions (Medical)	0.28	0.25
Technology Licensing Office Age (2007 – year instituted)	0.21	−0.02
Technology Licensing Office Licensing Full-Time Equivalents per Expenditure	0.34*	0.61**
Technology Licensing Office Other Full-Time Equivalents per Expenditure	0.41**	0.16
Adjusted R^2	0.55**	0.54**

*p-value <0.1, **p-value <0.05
Values are standard coefficients

The first path is a very attractive invention or technology, for which a licensing opportunity is identified at an early stage of the licensing process. The three short lag periods of 5-year lags from expenditure, 3 years from patent, and 3 years from licenses and options exercised could be related to this pattern. The second pattern is a delayed or shelved invention [45]. There could be many reasons for delay. For example, a technology or disclosure may need further breakthrough, market needs may not be clear enough, faculty inventors may not be actively involved in licensing, or an academic institution may be conservative in licensing and negotiation [15, 46, 47].

The longer lags, such as 8 years from expenditure, 11 years from patent application, and 8 years from licenses and options exercised, could be associated with the second pattern. Start-up at t-0 has the highest effect on licensing. This is consistent with findings from other researchers [23, 48–50]. Generally, universities prefer a short-term cash reward from a spin-off, rather than long-term royalty or equity.

Research institution licensing offices should consider the time lags in licensing and incorporate these lags into their licensing strategy. Depending on the policy and financial goal of the university's licensing, the licensing office can develop a licensing portfolio for an invention so that the desirable cash flow of multiple licensing negotiations is achieved. This also suggests that university administrators and stakeholders outside of the university must understand that licensing is a time-consuming process. Therefore, they should not enforce a certain licensing format or apply a faculty reward system with a short time frame.

20.6.2 Research Performance, Academic Prestige, and Licensing Performance

Siegel et al. [30] suggested that a trade-off exists between university technology commercialization and research performance. On the other hand, some other studies found that higher-quality faculty members, who may bring better-quality research, tend to be reluctant to spend their time in the commercialization of their findings [45]. If faculties get involved in commercialization activity, they may spend less effort or time on their primary duties of teaching and research [12].

The present study found that licensing variables have a positive correlation with TLO variables, ranking, and journal articles. Journal articles and average ranking indirectly reflect research intensity and its quality. The results show that an institution with high research performance has more disclosures and start-ups. Moreover, a better-than-average ranking is significantly related to more patents issued. This shows that patents issued (though not patent applications) reflect the quality of inventions. The effect of the existence of a medical school on disclosure, patent applications, and start-up is negative. This shows that, although a medical school spends more research funds, the quantity of new inventions is relatively small, resulting in fewer start-ups.

One surprising result is that academic prestige, as measured by academic ranking, is negatively related to both licensing efficiency and efficiency change. However, the study also found that not only highly prestigious institutions such as the California Institute of Technology and the Massachusetts Institute of Technology but also less prestigious ones with lower research expenditure presented high licensing performance. Considering that most of the super-efficient institutions are prestigious ones, the result does not strongly prove that less-prestigious institutions have better licensing performance. Instead, it can be understood that not all prestigious institutions emphasize licensing, and therefore they could improve their performance significantly. Another possible interpretation is that the negative relationships reflect the dominant catch-up efforts of less-efficient institutions. A study by Baldini et al. [18] found that institution size relative to total budget does not have a statistically significant relationship with patents. Therefore, an effective licensing process and organizational support are very important to achieving better licensing performance.

20.6.3 Effort, Age, and Licensing Performance of Technology Licensing Offices

The results of the present study support the findings of other studies [12, 13, 15, 17, 49, 51]. Although the effect of a TLO's age on efficiency and efficiency change is not statistically significant, TLO licensing FTEs and other FTEs relative to expenditure contribute to better licensing performance. The regression result of the study is illustrated in Fig. 20.4.

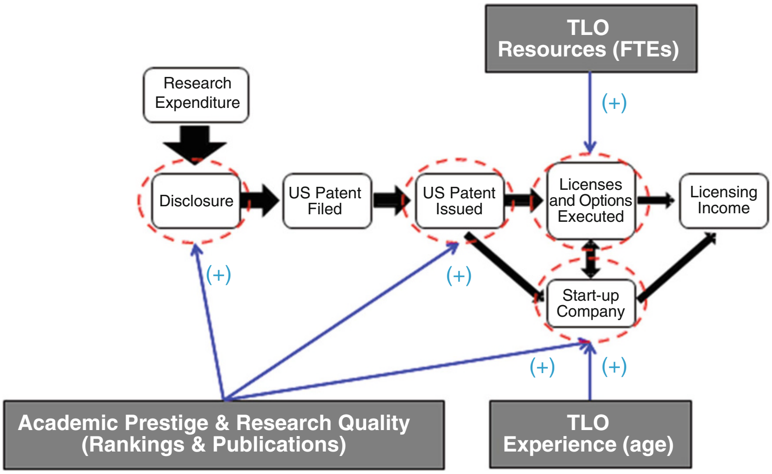

Fig. 20.4 Institutional characteristics and licensing outcomes

The study also confirms that TLO age is associated with the number of start-ups. TLO age represents the history of a TLO and therefore its experience. A more experienced TLO with a long history presents good support for start-ups. However, more human resources (licensing and other FTEs), rather than experience (TLO age), are related to more licenses and options executed. This supports the idea that TLO size is important to an institution's successful licensing negotiation.

20.7 Recommendations

This paper suggests recommendations for academic institutions' strategy improving licensing practice based on the findings from the study. Academic prestige and research quality are related to the early stage of the licensing process, disclosures and patents, and start-ups. Therefore, institutions' continuous effort improving their research productivity will improve these licensing outcomes. Therefore, overall licensing outcomes will be increased along with fundamental institutional improvement in research quality and increase in research funds, which require a long-term strategy plan. On the other hand, short-term strategy of hiring skilled licensing staffs could increase licensing agreements; thereby, maximize utilization of the intellectual properties given the current institutional research capability. The strategies by institutional goals are summarized in Table 20.6.

Table 20.6 Institutional strategies improving licensing practice

Institutional goals	Strategies
Disclosures and patents	• Focus on academic prestige and research quality
Start-ups	• Focus on academic prestige and research quality • Focus on licensing staff (experience)
Licensing agreements	• Focus on licensing staff (number of FTEs)
Increase licensing outcome	• Academic prestige (better and more research) • More research funding
Improve licensing productivity	• Focus on technology licensing office

20.8 Conclusion

The present study outlines an approach for assessing the licensing performance of academic research institutions over time and explores these performances with regard to related institutional characteristics. For this purpose, the study developed two new methods: a time-lag identifying process using a distributed lag model and an unstructured regression coefficient structure, and a three-stage modified super-efficiency DEA model resolving computational infeasibility and zero-data issues. The results provide stakeholders in government agencies, companies, research organizations, and other universities with a better understanding of licensing practices, filling in the gaps identified by the literature review.

The time-lag identifying process developed in this study provides a better approach to measuring the possible time lags in licensing or commercialization. The time lags identified by the approach also could enable researchers to build a more elaborate and realistic model for evaluating academic research institution technology licensing.

Although the efficiency of a benchmarking study identifies best practitioners and inefficient institutions, there exists a limitation in implementing the results in the real world and in understanding the rational reasons for low or high efficiency. Therefore, additional analysis, such as regression, has been performed to explain the characteristics influencing efficiency. However, because the efficiency score created by stochastic frontier estimation or data envelopment analysis puts all unknown specifications of an institution into a single number, the identified relationships between the efficiency score and organizational characteristics also includes aspects that are ambiguous for interpretation and application in the real world.

The approach outlined in this study could overcome those limitations by exploring organizational characteristics and various aspects of efficiency (average efficiency, efficiency changes, technical changes, and Malmquist Index) over time. The approach provides insight into organizational practice and related polices and characteristics by examining their relationships with the efficiency and patterns of ARITC.

For this purpose, this study developed a three-stage super-efficiency VRS model, which overcomes the current limitations in DEA theory. First, the study resolves computational infeasibility caused by an extreme data point, when variable returns to scale is applied. For this purpose, the strengths and limitations of the three current approaches [39–41] have been discussed and the models have been tested using published data. Second, a nonradial model has been applied to deal with zero-data issues.

The following areas are suggested for future work. First, case studies of academic research institutions' technology commercialization practices could help increase model reliability and improve understanding of certain unique institutional situations that could not be observed in this study. Second, the licensing time lags identified in the study need to be explored further by using case studies of several academic research institutions. Finally, this study explores a limited number of institutional characteristics that influence licensing performance. A dedicated survey could help to identify other characteristics that explain time lags and licensing performance.

Appendix 1

The two decompositions are:

$$M = \frac{D_v^{t+1}(x^{t+1}, y^{t+1})}{D_v^t(x^t, y^t)} \times \left[\frac{D_v^t(x^{t+1}, y^{t+1})}{D_v^{t+1}(x^{t+1}, y^{t+1})} \times \frac{D_v^t(x^t, y^t)}{D_v^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} = \mathrm{EC}_v \times \mathrm{TC}_v \quad (20.2)$$

$$\mathrm{EC}_v = \frac{D_v^{t+1}(t+1)}{D_v^t(t)} \quad (20.3)$$

$$\mathrm{TC}_v = \left[\frac{D_v^t(t+1)}{D_v^{t+1}(t+1)} \times \frac{D_v^t(t)}{D_v^{t+1}(t)}\right]^{\frac{1}{2}} \quad (20.4)$$

where D = efficiency, equivalent to $\varnothing$, $D^t(x^t, y^t) = D^t(t)$: distance (efficiency) of a technology (x^t, y^t) to the frontier at time t, $S^t(x^t, y^t)$ = scale efficiency change of a technology (x^t, y^t), *EC* efficiency change, *TC* technical change, subscript v = DEA model based on VRS (variable returns to scale), and subscript c = DEA model based on CRS (constant returns to scale).

Appendix 2

Table 20.7 Average efficiency change, technical change, and Malmquist Index scores of the 46 institutions

Institutions	Average over the periods			Institutions	Average over the periods		
	EC	TC	MI		EC	TC	MI
Baylor College of Medicine	1.26	1.06	1.41	Oregon State Univ.	1.21	1.20	1.40
Brigham & Women's Hospital, Inc.	0.98	1.22	1.16	Penn State Univ.	1.08	1.08	1.13
Brigham Young Univ.	2.61	1.59	6.12	Rutgers, The State Univ.	0.97	1.19	1.11
California Institute of Tech.	1.21	1.04	1.30	St. Jude Children's Research	1.18	1.18	1.31
Case Western Reserve Univ.	1.07	1.22	1.19	Tulane Univ.	0.92	1.15	1.02
City of Hope National Medic	1.01	1.15	1.05	Univ. of Akron	1.23	1.23	1.41
Clemson Univ.	1.02	1.11	1.02	Univ. of Arizona	1.06	1.08	1.14
Colorado State Univ.	1.23	1.15	1.22	Univ. of Cincinnati	0.89	1.17	1.01
Dartmouth College	1.50	1.20	1.77	Univ. of Connecticut	1.02	1.19	1.17
Florida State Univ.	1.30	1.08	1.32	Univ. of Dayton	0.93	1.22	1.10
Fred Hutchinson Cancer Res.	0.99	1.18	1.18	Univ. of Delaware	1.07	1.21	1.25
Georgia Inst. of Technology	1.16	1.12	1.21	Univ. of Iowa Research Fdn.	1.08	1.15	1.19
Harvard Univ.	1.07	1.10	1.19	Univ. of Maryland, College	1.44	1.16	1.47
Indiana Univ. (ARTI)	1.19	1.17	1.29	Univ. of Michigan	1.17	1.14	1.41
Johns Hopkins Univ.	1.11	1.14	1.25	Univ. of Minnesota	1.12	1.06	1.19
Massachusetts Inst. of Tech	0.95	1.11	1.05	Univ. of Oregon	1.06	1.17	1.13
Mayo Foundation	1.08	1.13	1.15	Univ. of Southern California	1.02	1.06	1.07
Michigan State Univ.	1.05	1.10	1.11	Univ. of Texas Southwestern	1.03	1.20	1.19
National Jewish Center	1.05	1.23	1.31	Univ. of Utah	1.16	1.13	1.20
New Jersey Institute of Tech.	1.33	1.26	1.75	Univ. of Virginia Patent Fdn.	0.95	1.10	1.02
Northwestern Univ.	1.16	1.16	1.29	Vanderbilt Univ.	1.11	1.14	1.22
Ohio State Univ.	1.03	1.12	1.17	Wake Forest Univ.	1.33	1.16	1.39
Ohio Univ.	1.00	1.20	1.08	Washington Univ.	1.06	1.12	1.15

EC efficiency change, *MI* Malmquist index, *TC* technical change

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Part V
Managing the Engineering Enterprise

Introduction

In every organization, there is a need to execute different initiatives such as projects in order to evolve the organization and support the achievement of organizational and strategic initiatives. These initiatives are impacted by a wide variety of different factors, including economic decision-making, leadership styles, change management, and the components of quality management. Therefore, it is essential to evaluate and understand the relationships that economic decision-making, leadership styles, change management, and the components of quality management each have on an organization's ability to plan and execute initiatives such as projects. This section is organized into four segments, those being: discussing the implications that economic decision-making has on the project manager, the role and impact that leadership styles have on a project manager's ability to plan and execute a project, a comparative analysis of the similarities and differences of different change management models and their applications to project environments, and finally, the components of quality management and the relationship they have on planning and executing a project.

The business managers and owners have an agent–principal relationship, as the owners expect the managers to maximize returns. Managers must avoid conflict with their principals, as they must make important decisions to keep a project on the right track. Good decision-making is vital to a project's success, and it is of utmost importance to the role of a manager. Also, managers must supervise the project team, inspire it, and supply them with the proper resources. It is important for a manager to create an environment that encourages the full realization of the project objectives. A project is only a short-term task to achieve a particular outcome, so it must be done in a way that stays within the resource limitations. Any decisions must include effectively distributing resources to the necessary project units.

Over the past decades, leadership has become a key point of focus, as we can generate the best definition of it from studying any previous research. Since there are so many different types of people, personalities, and industries, there is an abundance of leadership styles. Every leadership style has its own definition and qualifications, but there are overlaps between these styles. Thus, some of this section presents research that examines these overlaps, as well as what influences the leadership role in a project environment. We generated three tables to classify, describe, and identify the factors of the leadership styles. With these three tables, we can discover the most effective aspect of the leadership role in project environment.

Change is both welcomed and feared by people, as it can bring great opportunities, but there can also be risks. As of now, the change management is applied to each aspect of every business sector, as the world is ever-changing with its opportunities and risks. This is where change management comes into play for many researchers in the literature field. Our study compares several leading change management model to find their similarities and differences. The Kotter's change model, the ADKAR, and the Lewin's change management model have similar stages, but there are also many differences. Thus, we cannot determine which model is most effective because they emphasize different things and feature different application circumstances. Our study shows that Kotter's model focuses on implementing the organizational change from the viewpoint of senior leaders, so this model is more effective with senior management. Furthermore, the ADKAR model highlights large businesses, while Lewin's model focuses on reducing the force of resistance. Overall, the change management is vital to the future of technology and management.

If a manufacturing organization wants to foster more competitiveness, then there must be a high-quality management system. TQM (Total Quality Management) has grown to be a vital tool to help manufacturing organizations grow and find support. Since the competitive business environment is always increasing, then there must be a good foundation for implementing TQM. Research will show that as one must be aware of and evaluate the pillars of quality management: creating a quality management environment, teamwork, tools for quality control, supplier relationships, and focusing on customers. The findings illustrate that aspects connected to these pillars are evident in the studied organizations.

The subsequent chapters in this section will provide further details and discussion into the relationships that economic decision-making, leadership styles, change management, and the components of quality management each have on an organization's ability to plan and execute initiatives such as projects.

Chapter 21
Implications of Economic Decision-Making to the Project Manager

Brian J. Galli

21.1 Introduction

The managers and owners of the organization do exist in an agent-principal relationship, whereby the former is expected by the latter to maximize their return. However, for managers to avoid conflict with their principals, they have been tasked with making critical decisions to ensure that the project is executed in accordance with the established plan. Decision-making is critical to the success of any project, and it is among the most important roles that a manager commits to. The manager has to lead and motivate the project management team and must be the source for the right equipment and materials. Also, the manager must create an environment conducive to the full realization of a project's primary goals. Since a project is a temporary undertaking that is meant to achieve a specific agendum, it has to be executed in a manner that is fully cognizant of resource limitations. Therefore, the decisions that are made have to involve the effective allocation of resources to the various units of the project.

Traditionally, managers are expected to plan, organize, command, coordinate, and control functions. In accordance with Henri Fayol, a manager is supposed to look ahead and generate good plans of action that address tough problems. In the process of executing his roles and functions, the manager has to make important decisions that have an equal weight of spanning success or failing the organization. Therefore, decision-making has become a very central and critical function of management in the contemporary business world. At all times, project managers have to make all manner of decisions, given their priority and importance. For the best decisions, managers need sufficient and correct information. This will

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help to make effective judgments for better decisions. Essentially, managers must do what is best for their superiors because they act as agents for their principals [1].

As agents, managers are expected to maximize the returns from shareholders' investments of the various organizations for which they work. However, managers deploy several tools to keep track of all projects that they are involved in at any particular time. Nowadays, it is a common practice for managers to keep records either digitally or manually. However, with technological innovation in the telecommunication industry, every organization has found it necessary to implement current technologies and equipment for keeping data and statistics. The introduction of computers in storing data makes it easy to access and retrieve information, which facilitates decision-making [2].

21.1.1 Background to the Topic

Project management is a vital aspect of an organization, as it can influence liabilities and revenues. Also, project management determines how customers receive the business. Corporations may just focus on one project at a time, but larger businesses could juggle many. One must note that projects are short-term undertakings to reach a larger goal eventually [3].

Project management is, therefore, a detailed plan as to how an organization or business would want to achieve certain goals and objectives. Successful project management has to contain other elements, such as scope, resources, time, and money. Above all, a project manager plays a crucial function in ensuring a successful project. A project manager plays many roles, such as defining the scope of the project, which reduces a huge project to a set of manageable tasks. It also acquires the most appropriate resources that will enable the team to perform effectively.

Additionally, the manager is supposed to set the final goal of the project and motivate the project team to unleash their full potential to complete the project in time. As such, the project manager must always inform all stakeholders of progress on a regular basis. He must assess and monitor every risk that is associated with a project beforehand to seek ways to mitigate them. In order to perform all of these functions, a project manager has to acquire key competencies, such as leadership, effective communication, influence, negotiation, conflict management, planning, contract management, estimation, and creative thinking. This set of skills is critical and key to the decision-making role of a project manager [2].

Decisions that follow the way to reaching an ultimate goal drive projects, as there are many decisions that go into a project. Most specifically, the requirements, choice of resources, design approach, and many other issues are important decisions to make. There are three ways to make these decisions: by majority, by consensus, through authority, and within a group. As for managers, they need to apply numerous techniques, such as avoiding conflict, illustrating assertiveness, compromising, having dialogue, debating, and facilitating [3].

As much as there is no best technique that has been agreed upon to make the most appropriate decision, any effective manager ought to make tough decisions for the prosperity of the company. For instance, consensus decisions ensue when every member of a project management team agrees to a single outcome. The outcome might not be favorable and pleasing to everyone, but all of the people involved consent to it and support it, provided they agree unanimously that it serves the objective. This project will seek to understand the various implications of economic decision-making on project management by discussing the various techniques of making decisions in the organizations.

21.1.2 Problem Statement

Decision-making is an important role for a manager at any one point in time because these decisions impact how the organization performs. In a nutshell, managers' decisions have the ability to inspire success or to break the organization. Economic decisions made by managers, in most occasions, have implications that can either be positive or negative. However, managers have been known to be planners, organizers, controllers, and coordinators. All of these functions involve decision-making, therefore making it one of the critical roles that a manager performs in the organization [4].

Most of the times, the decisions made by managers do not please everybody, so a manager has to bare a brave heart. Again, all of the blames and praise go to the manager, as the buck stops with him or her. If the manager makes a wrong decision, then the organization stands to lose reputation, image, and profitability. However, if the decisions turn out to be right, then the organization benefits from improved reputation, image, and productivity. The research paper will, therefore, seek to understand the negative and positive implications on the organization that are caused by economic decisions made by project managers.

21.1.3 Research Hypothesis

Decision-making is a critical role in the success of an organization, and without proper decision-making, projects will not run appropriately and fail. Further, consensus decision-making is the most effective way of achieving results. However, there can be so many people supporting an idea that ends up being wrong, even after a minority expressed their displeasure at such an idea. Decision-making can be such a challenge for both the manager and the entire organization. Though the majority decision has its inefficiencies, it acts as a demonstration of leadership within a company [3].

21.1.4 Originality

This work has been prepared after an extensive research has been conducted on the topic area and, therefore, does not consist of data that has been used without acknowledging the legal owners of the information.

21.1.5 Contribution to the EM Profession and Research Field

Most of the time, people think that the manager's work stops at the point of making decisions, this fallacy will be demonstrated from the text and findings. For instance, a responsible manager, before making any decision, stops at the point of making decisions alone, but this is not true. For instance, a responsible manager, before making any decision, should consider and evaluate their implications. The results of this paper shall help to shed light into the implications of all decisions that a manager can take because they can either be positive or negative. Also, it will make the reader understand that the managers' roles are not restricted to planning, controlling, coordinating, and organizing [5].

21.2 Theoretical Review

21.2.1 The Expectancy Theory

The expectancy theory advanced by Vroom assumes that behavior results from conscious choices among alternatives that function to maximize pleasure and minimize pain. Therefore, employee performance relies on the individual's abilities, experience, knowledge, skills, and personality. Vroom further stated that a person's motivation links effort, performance, and motivation. Effectively, managers can combine work goals with the goals of employees at any time. Doing this makes the employees feel part of the organization and, therefore, appreciated by the management [2].

Vroom pointed out that expectancy is the belief that increased effort, which can lead to an increased performance. For instance, if an employee perceives that by working hard, he will become better. However, this is affected by the availability of the right resources, such as raw materials and a proper set of skills for doing the assigned duty or job. Additionally, having the necessary support from the management, according to Vroom, ensures that an employee's performance improves tremendously. On the other hand, instrumentality is the belief that if an employee performs betters, then he will get a valuable outcome to be received as an appreciation [4].

21.2.2 Literature Review

21.2.2.1 What Is a Critical Decision?

The critical nature of a decision hugely depends on the magnitude and anticipated payoff of the decision. Therefore, there are several reasons that influence the criticality of a decision taken by a manager. Decisions that create an impact in a department only might have little significance compared to a decision that affects the whole organization [5].

21.2.2.2 The Roles and Duties of a Project Manager

Project managers are meant to carry out a project through authority and responsibility from the project board. They must set the goals and objectives for a project; therefore they are the project team's leader and manager. There must be open communication within the organization, which is up to the project manager to maintain daily. Thus, a project manager needs to communicate effectively so that members of the team can know what is required.

There are many responsibilities for a project manager to fulfill. First of all, project managers need to create and apply the necessary project management standards. Second, project managers need to manage the manufacturing of the necessary deliverables. Thirdly, project managers need to plan and supervise the project. They must even adopt any delegation and project assurance positions in the reporting standards. Also, project managers supervise the progress in general and the use of resources that are usually limited. Project managers need to apply and take on both technical and quality strategies and standards for the project to succeed. Lastly, project managers gain support and counseling to maintain control over the project [4].

For one to be a project manager, he or she needs a given set of skills and attributes, such as establishing a good working relationship with the project team and the management, directing, managing, and motivating the team that is tasked with managing the project. Additionally, a project manager should develop and maintain agreed project plans and detailed stage plans. He must understand and apply business cases, as well as risk management processes. Also, he should tailor expert knowledge to meet specific circumstances and situations. Furthermore, planning and managing deployment of physical and financial resources to meet project milestones is important. Lastly, a project manager should possess the ability to build and sustain effective communications with other roles involved in the project [5].

It is important to note that a project manager should be appropriately trained in suitable project management techniques and processes. For substantial projects-accredited training, the organization should ensure that it facilitates the training of personnel and managers. Training equips the project manager with the necessary set of skills that will enable him or her to perform duties appropriately. More importantly, a project manager should have the much-needed communication skills. Effective communication skills are critical in ensuring that a project manager communicates the organizational or project goals and objectives to the team members. A good communicator is also a good leader, who has the ability to motivate the team members to produce their best towards the attainment of the project in the shortest time possible [6].

21.2.2.3 What Constitutes a Good Decision?

The essence of decisions is to drive action, so a decision that is made but not acted upon becomes useless and meaningless. Sometimes, a decision can be made and implemented, but it can fail to achieve the intended objectives. However, a decision can still be considered good even when it fails to achieve its objectives, as a well-made decision to operate on a patient can go well even if the patient dies. A good decision has to integrate all of the appropriate tools and techniques that make good use of all the available information. Additionally, this decision is based on intelligent analysis that engages the right kind of people. It is still important to note that decisions are made based on assumptions, and such assumptions are significant because of the unpredictability of the future [5].

In essence, the decision to pursue the creation and introduction of a new product can be well-made and considered, but the resulting product can be a complete failure if the market does not accommodate it. The product can fail because the market had changed in a manner that decision-makers did not anticipate when arriving at the decision. However, if decision-makers took their time to conduct some small research, they could possibly anticipate the change in the market. In the process of making a decision of any nature, it is critical to note that intelligence, method, objectivity, and patience are key decision making factors [4].

The process of making decisions can be tiring, and the decision-makers can be tempted to rush to complete the project. Sometimes, team members might omit some essential steps along the way, which can lead to a hurriedly made decision that will not constitute a good decision. Therefore, patience is key in overcoming the desire to get the decision-making over with and to eliminate uncertainty. It further allows decision-makers to agree with uncertainty and to work towards unraveling the mystery about the future. On the other hand, objectivity allows for the questioning of every process and activity, and it ascertains an idea's worthiness.

21.2.2.4 What Are the Benefits of Involving Team Members in Decision-Making?

There are several benefits that accrue from involving others in the process of making a decision that will affect the organization at large. The workforce represents a rich source of ideas and knowledge; it is a resource that is, most of the time, ignored.

In fact, involving the workforce in a decision-making process does not only motivate them but it also inspires increased productivity. As a leader, a manager is expected to bring all of the stakeholders onboard whenever the organization wants to make an important decision. Additionally, there are several benefits that accrue from involving employees in decision-making. These benefits include improved productivity, morale, better utilization of internal resources, better teamwork spirit, increased employee relations, different angles, and improved trust [6].

Trust is an important issue in motivating the staff to work hard towards achieving the objectives and primary goals of a project. Organizations that formulate decisions as they keep their employees in the dark have the possibility of losing them to competition because of the personnel's trust and confidence in the process of making a decision. Employees may believe that when a company keeps its decision secret, these decisions have negative effects or outcomes on the staff. Therefore, engaging the whole organization in creating a decision induces some sort of transparency in the workplace. When there is transparency in the organization, employees will endeavor to unleash their full potential to increase productivity [6].

Moreover, businesses need employee relations to create the necessary teamwork to realize project objectives. Employees should be involved in producing policies and important decisions to feel valuable to management. Thus, employees will apply his or her all to generating organizational objectives. If an employee can see his input put into use then he will feel valuable to the company by making a difference. Assisting staff understanding and knowing that they are needed and valued by the entity is a crucial component of introducing competent workplace relationship. Thus, a manager is expected to explain to his or her employees how he or she considers their contribution when arriving at decisions.

The organizations operate in an environment that is faced with resource constraints. The manager, as a decision-maker, has to apportion them to the various components of the project appropriately for effective performance. However, in the contemporary business world, many firms have embarked on outsourcing to solve resource constraint problems. Involving the employees in the process of making decisions saves the organization time, money, and offers the corporation long-term reliable assistance from those who associate with the association [1].

21.2.2.5 Managers as Decision-Makers

Managers play a significant role in the motivation of employees to work extremely hard towards attaining the objectives and goals of the project. In fact, motivation forms the most powerful emotion, which every staff member should carry to the workplace. The management stimulates motivation in the job place through a shared vision and effective communication. As such, great managers bring to the workplace fundamental communicative and engaging skills that help to increase cohesion and teamwork in the entity. Managers can, therefore, always learn how to inspire motivation in the workplace. Traditionally, managers were perceived to induce fear in the workers, overworking and distressing the staff. Also, team leaders, managers for that matter, are often discouraged by the dismal performance from employees, which makes employee motivation significant in improving performance of the entity [7].

The question of how managers can motivate employees can be answered that every employee is already motivated. The only challenge that any manager faces is to tap into the potential of this motivation to bring about success in the organization. The manager is also in charge of key environmental factors that necessarily motivate the staff. As a manager, he or she controls the nature of his or her relationship with every employee. More importantly, a manager can create a workplace environment, as well as organizational culture, that motivate and engage the workers. The environment being talked of ensures that employees are trusted, treated like adults, and are not micromanaged. These workers are entrusted with the values, strategic framework, mission, and vision, within which they are expected to accomplish their duties [8].

The employees also expect to receive frequent and constant communication from their managers regarding the work they were hired to perform. The managers should encourage the workers to speak up about what they believe in, as it concerns solving several problems that they encounter in the execution of their duties and responsibilities. Moreover, in a bid to involve the employees, the managers need to brief them on any key financial information, so that they are not kept in the dark on any matter that relates to the organization [9]. By praising something that an employee has done exceptionally well, the manager motivates them to continue with the good performance. The manager can also offer flexible scheduling to the staff members to give them time to relax. Last but not least, the management plays a critical role in hiring talented employees and putting forward measurable goals [7].

21.3 Research Methodology

21.3.1 Introduction

This chapter shall describe the method that was used to collect, present, and analyze data. Additionally, this chapter will bring forth the ethical considerations in the research and collection of appropriate data. The validity of research instruments deployed in the study shall be discussed in this chapter.

21.3.2 Research Approach and Design

A descriptive survey was selected to collect data, since it provides an accurate and reliable portrayal of the characteristics, such as behavior, knowledge, beliefs, abilities, and opinions relating to a specific situation. The design is chosen to determine the implications that are caused by the decision-making role of a manager in the organization. The study will not involve using questionnaires to collect data. Instead, it will rely on secondary materials on the same topic that are available from various sources, such as the Internet and university repository. Such a method is chosen because it is cheap and less time consuming [10].

21.3.3 Data Collection

21.3.3.1 Data Collection Instruments

Instead of a questionnaire to collect data, the researcher opted to use secondary information that is contained in earlier research reports that are available in both print and online sources. Since the research will be based on the analysis of secondary sources, these sources are classified into two main categories: published sources and unpublished sources.

Published Sources

Published sources are majorly international, semi-government, government, national, expert committee reports, trade associations' reports, and corporate bodies. These reports contain data from different fields, such as income and quarterly reports. The study has analyzed annual financial reports that are issued by major corporations to appropriately treat their employees. The corporations considered in this study include Apple and Microsoft.

Advantages of Using Secondary Sources

Secondary data sources save a researcher time that he will use in collecting data. The time saved is, hence, applied in the analysis of the information obtained.

- Ease of accessibility of secondary sources of data as a result of modern technology
- Saving of money by the researcher
- Feasibility of both longitudinal and international comparative studies
- Providing new insights
- Disadvantages of secondary sources
- Data inappropriateness
- Lack of control over the quality of data obtained via these means of research

21.3.4 Data Collection Procedure

The researcher identified the companies from which to collect data and searched over the Internet for their published financial statements for the years 2016–2017. Furthermore, the researcher looked at Apple and Microsoft's employee motivation plan.

21.3.4.1 Reliability and Validity

Reliability

Reliability involves the level of consistency that a research instrument calculates attributes to be measured. It is appropriate to use secondary sources, as it can save time, money, and resources for the researcher, who will not have to conduct the study alone [10].

Validity

Validity of any research instrument can be defined as the degree to which an instrument measures the intended item. It also refers to the extent to which an instrument represents the factors placed under study. In order to achieve content validity, the sourcing of secondary data included a wide range of topics to understand the implications of economic decision-making by project managers on the success of a particular project.

Research areas were expanded to include all of the fields covered in the literature review to ensure that they represent enough of what really is the implication of involving employees in the process of making pertinent decisions. Furthermore, validity was achieved by ensuring consistency with the key words to search on the Internet of everything. The researcher conducted data analysis concurrently with the search of information. Only websites that were considered authentic were googled to derive the wanted information.

21.3.5 Ethical Considerations

To conduct research, one must be diligent, proficient, and honest to identify, protect, and respect human rights. Complying with ethical standards of gathering data entails that the researcher is limited to searching websites that feature the authors' studies. Also, this study cited the websites' information, and their owners recognized what was needed to not plagiarize. There was written permission to perform the research on this topic from the department and the university faculty.

21.3.6 Data Analysis

After collecting data, it was organized and analyzed by the use of descriptive statistics. Then, it was presented in tabular form, as well as through the use of pie charts.

21.3.7 Conclusion

This chapter described the research methodology that was employed by the researcher, including data collection instruments and ethical standards to ensure study reliability and validity.

21.4 Findings

21.4.1 Introduction

This chapter illustrates the researcher's findings from the study. Preferably, Apple desires a workplace to encourage employee creativity. Thus, Apple merges extrinsic and intrinsic motivation for employees to be empowered and inventive. Apple uses many methods to motivate employees. For instance, Apple once rewarded executives with a recognition bonus between 3 and 5% of their base salary, even though the project target was not achieved. Clearly, upper management understood the group's efforts. There is also the motivating incentive of giving a discount on Apple products for employees, such as a free iPhone or iPod Shuffle. Receiving products instead of money can better motivate an employee, as many Apple employees want to see the outcome of their efforts. It is usually a cheaper decision to give products instead of raises, as Apple has recently granted more vacation days for a strong performance with product sales. Overall, these are extrinsic examples of Apple's motivation techniques [7].

Employee motivation is also derived from the corporate culture. For the most part, Apple employees are dedicated to their work, as they enjoy the monotonous encoding. It may even be insightful to view the intrinsic forces that drive Steve Jobs. According to Jobs' Stanford commencement speech, he is fully aware of his own mortality, but this inspired him to fulfill his dreams. Thus, profit did not drive him to create his innovative products: his personal desires did [8].

21.4.2 Management's Role in Motivation of Employees

It is important for businesses to succeed by management creating a motivating environment for employees. Managing change means that management can preserve and attract more dedicated employees to meet set objectives [9]. Additionally, the management is responsible for setting an organization's goals and objectives, especially as it concerns a particular project. The ability to inspire the employees to equally contribute to attaining the corporation's measurable goals and objectives is a powerful tool. Motivation in management is the description of ways in which managers use to promote productivity in their employees. Apple and Microsoft's management recognize that employees constitute the most critical component of the organization's success. Thus, it is the responsibility of a manager to motivate the employees to unleash their full potential and skills to attain the much-needed success. However, motivation is considered as the effective ways that managers and the organization use to encourage its staff to become productive [11].

21.4.2.1 How Employees Are Motivated by Corporations

According to Vroom's expectancy theory, an employee anticipates some reward for doing his work well. The management, therefore, plays a significant role in ensuring that the employees get the right material and appropriate environment to perform their duties with diligence and satisfaction. Motivation is an important aspect of ensuring employees' hard work to achieve their aspirations, as well as to fulfill the demands and needs of a project. Applying the expectancy theory in the business environment has been known to produce significant results, especially where profitability is concerned [8].

Apple applies Abraham Maslow's hierarchy of needs in successfully motivating its employees to produce the best performance. Apple has become a leader in the technology industry through setting its basic average salary at $108,000 annually, which satisfies the low-order needs of its staff. As long as the management of Apple Corporation fulfills physiological needs, the employees will become effectively motivated. This will increase productivity and profitability. In essence, innovation ensures that an organization achieves its objectives and goals, while ensuring sustainability in the industry [12].

Apart from salary emoluments, Apple has improved the range of factors that fulfill the employees' need for protection by embracing training employees on all kinds of hazards. Also, Apple ensures that employees can protect themselves both at the workplace and at home. In order to satisfy the esteem need, Apple has endeavored to award its top management with a bonus salary increment of between 4 and 5%. Apple's workers can receive a free iPhone as one way of motivating its employees who have managed to finish their works. Furthermore, Apple has tried to increase the opportunities for employees to participate in education and development programs, so that they can enrich themselves in the workplace [11].

21.5 Discussion

21.5.1 The Importance of Intrinsic Motivation

Intrinsic motivation is the use of internal rewards to help employees to take pleasure in their work because they feel fulfilled by doing it. A project manager's primary objective is to generate great products, so he must also ensure that employees are proud of their work and contributions [9]. By falling in love with a brand, an employee will put his best foot forward to ensure that everything goes as planned. More importantly, the employees perform their duties diligently without feeling forced. If they feel forced, then they will not commit to ensuring that the objectives of the project are attained no matter what it takes. In fact, an organization benefits a lot from making sure that its workforce becomes the best that they would want to become [13].

A manager should also ensure that its workers are accorded jobs that are not too easy or too difficult to do. Challenging tasks instigate creativity and innovation on the side of employees, which increases productivity. Pushing the employees to their maximum limit helps them to unleash their full potential to become better employees. On the other hand, the workforce feels recognized and respected, as they get to understand that the company's management believes in their potential [12].

The management of a company such as Apple hires excellent people, gives them a portion of the business, and makes them run it. In turn, this allows them to make good and informed decisions, but the decisions can sometimes fail the unit that is managed by the new employees. The management does not, in any way, bush the workers, but it recognizes failure as one form of learning for staff. At Apple, the management believes that employees can learn effectively from their mistakes, and they can plan and formulate the best decisions. In order to attain this level, the managers and management at large ensure that the new employees understand every aspect regarding the business structure. When the employees get to understand everything about the business, they will take up their work seriously because they feel part of the company. Additionally, they get the feeling of sharing the ownership of the organization, as their input to the success of the corporation is recognized and rewarded [13].

Apple further conducts a regular review of its business, including the products under development, those already in the marketplace, and those that the marketers are experiencing difficulties in selling. This is conducted to ensure that all employees are on the same page. Eventually, the employees will feel respected and not left behind, as they will put forward a concerted effort towards the attainment of organizational objectives and goals. Thus, the intrinsic motivation of the employees is significant because it serves the interest of satisfying the internal needs of an employee [14].

21.5.2 The Importance of Extrinsic Motivation

Extrinsic motivation features the use of external rewards (money, gifts, and recognition) for employee motivation. Apple can attract and gain devotion from employees with these rewards, such as free iPod shuffles or iPhones with product discounts. This is a cheaper alternative than raises, as Apple has given recognition bonuses of 3% for executives, regardless of meeting the goal. Thus, Apple encourages team efforts and motivates workers with things like life insurance and longer vacations as of 2014 [12].

21.5.3 Retaining the Best Employees

Any promising organization needs to develop a framework identifying and retaining the most talented employees. This can be achieved through several methods and techniques, but more importantly, the career goals of an employee have to match what the company is looking for in a worker. It is common practice to witness employees, who have been in the company for some duration, leave for other organizations in pursuit of greener pastures. These employees happen to be the top talent in the organization and may feel unappreciated in the current organization, so they would want to look for the best, and most rewarding, opportunity [14].

In order for the organization to motivate the employees, they can challenge the workers weekly. Most times, top performers in the organization hate to be challenged, but if expectations are raised, job satisfaction increases, and so does the level of performance. Additionally, rewarding the employees for their attitude and not just for their skills is the best way of ensuring that staff members work towards attaining organizational objectives. Skills can always be acquired and learned at any time, but a great attitude is what it takes to inspire increased productivity and profitability. An organization should give their employees an opportunity and a chance to build and grow their careers, rather than just offering money. As such, training members helps to show them the next destination after they depart from the organization. Succession plans in corporations are as important as the level of profitability achieved annually. These plans assist in experienced employees passing on skills to the new and fresh talents hired by the organization [12].

The manager of a corporation should strive to make the workplace the best place for the employees to work and grow. The employees are an integral part and resource for the organization, so they deserve to be given an opportunity to brag. Apple, among other organizations in the world, has undertaken to reward their employees with an iPhone to give a taste of one of its leading products. Workers also deserve to be paid well, for the company cannot find a permanent and lasting solution in saving money through the payroll. Paying above the market rates can positively spark some sense of recognition and appreciation to attract and retain top talent in the industry [14].

The manager should not be seen as the only person making decisions in the organization but also as one that incorporates the ideas of employees. Therefore, the manager is expected to give every employee the ability and freedom to make their own decisions, as well as being responsible for all their actions. A manager is considered to be a leader as a boss, so he is supposed to communicate effectively to the project management team. Effective communication is key to ensuring that the employees produce at their best as they pursue personal and organizational success [15].

21.5.4 Need Satisfaction

Motivation fulfills individual and group needs. Each individual or group of individuals joins a business for personal gain. A manager's motivation function helps with such fulfillment [11].

21.5.5 Job Satisfaction

Motivation even creates job satisfaction, which leads to overall happiness for employees. Job satisfaction is a direct concern because it affects other important aspects [14]. Managers are mostly content with challenging that also entail imaginative thinking.

21.5.6 Productivity

The output contribution of an individual results from two variables: the ability to work and the motivation to work. With P as performance and ability and motivation as M, $P = A \times M$. Performance is not equivalent to the sum of a person's ability and motivation. Instead, it is the product of these two variables.

If the value of ability exceeds zero, then the level of performance increases with motivation. Productivity is the result of performance, so motivation must increase productivity [16].

21.5.7 Learning

Motivation assists the learning process in such a way that one cannot learn without it. Motivation keeps a person interested and eager to learn. Without the desire to learn, a person will not learn, even if they are capable and responsive to the learning process [14].Thus, a trainer must have select trainees and policies grounded in motivation, as well as practices to foster motivation.

21.5.8 Discipline

With motivation, one can become self-disciplined, which is usually taken as a negative characteristic. Subordinates tend to follow orders from superiors to avoid punishment, which is why motivation puts discipline into a positive light. Individual self-discipline is cheaper and leads to more success than the boss' discipline. Dedicated workers exemplify discipline as well, which they believe will further any self-interest [17].

21.5.9 Dynamism

Apparently, dynamism is a part of motivation, as rank and file workers and managers have kinetic energy when properly motivated. Such energy positively impacts business productivity and profits, as well as its industrial relations, public image, stability, and progress for the future. The focus of the content theories of motivation is to pinpoint what exactly motivates employees. Also, content theorists find the employees' needs or drives and how they affect their work behaviors. They focus on what goals the employees try to reach to feel satisfaction and to carry out their jobs well [17].

Money used to be thought as the biggest motivator (scientific management), but it became known that security and autonomous supervision motivates (human relations) [13]. Presently, motivation highlights the aspects of a higher level of need: esteem and self-actualization (Maslow), accountability, recognition, success and advancement (Herzberg), and growth and personal development [18]. However, process theories concentrate on identifying the variables of motivation and their relationship to clarify how behavior is energized, directed, sustained, and stopped.

21.5.10 Implications to the Field of IE/EM/PM

Decision-making is significant in project management because as agents, they are expected to maximize the returns from the investment of the shareholders of various organizations. However, managers deploy several tools to keep track of all projects in which they are involved at any particular time. Nowadays, it is a common practice for managers to keep records either digitally or manually. However, with technological innovation in the telecommunication industry, every organization has found it necessary to implement current technologies and equipment for keeping data and statistics. The introduction of computers in storing data makes it easy to access and retrieve information, so it facilitates decision-making [13].

Decision-making is a critical role in the success of an organization, and without proper decision-making, projects will not run appropriately and will fail. Furthermore, consensus decision-making is the most effective way of achieving results. However, there can be so many people supporting an idea that ends up being wrong, even after a minority expressed their displeasure in such an idea. Thus, decision-making can be such a challenge for the manager to make, as well as the entire organization. Though the majority decision has its inefficiencies, it acts as a demonstration of leadership within a company [19].

21.5.11 Applications to the Field of PM

Managers are critical factors in the process of making a project successful because they are in charge of making appropriate decisions. Additionally, the project manager's role is to always involve and engage with all employees. This will ensure that their views and ideas are incorporated into the decisions made by the top-level management. Intrinsic motivation uses internal rewards to inspire the employees to enjoy doing their work, since they are motivated and satisfied from within. Thus, when the employees achieve some level of performance, they feel gratified and fulfilled from within [17].

A project manager's primary objective with any project is to create great products, so employees need to love and feel proud of their work. If an employee loves a certain brand, they will make sure to stick to the plan. Also, an employee will not feel forced into their work, so they will commit to fulfilling any project goals. Any business greatly benefits from ensuring that a workforce is at its best [19].

21.5.12 Conclusions

Project management is, therefore, a detailed plan as to how an organization or business would want to achieve certain goals and objectives. Successful project management has to contain elements, such as scope, resources, time, and money. Above all, a project manager plays a crucial function in ensuring the project becomes a success, such as defining the scope of the project. Thus, the project manager will reduce a huge project to a set of manageable tasks, as well as acquire the most appropriate resources that will enable the team to perform effectively [17].

The manager is also supposed to set the final goal of the project and motivate the project team to unleash their full potential to complete the project in time. As such, the project manager must always inform all stakeholders of progress on a regular basis as they assess, monitor, and mitigate every risk associated with a project. In order to perform all of these functions, a project manager has to acquire key competencies, such as leadership, effective communication, influence, negotiation, conflict management, planning, contract management, estimation, and creative thinking. As one can see, this set of skills is critical to the decision-making role of a project manager [19].

Projects are propelled by decisions that follow the right channel and are aimed at achieving a specific goal. Many decisions must be made with a project, and majority, authority, in a group, and by consensus, can make these decisions. Managers apply assertiveness, conflict avoidance, compromise, dialogue, debate, and facilitation in these instances [16].

21.5.13 Motivating Employees at the Workplace

In the report, it is shown that motivators are exclusive to certain employees, so employee motivation can be complicated. It is important to find what drives individual employees to properly motivate them. One can simply ask employees what can be done to instill excitement in their jobs [15]. Every business must have a genuine interest in an employee's future, as an employee will change positively if their manager is interested in their career in the future. Employees must be mentored, and any additional training that can advance their careers must be done [19].

If a business focuses on the employees' interests then there need to be compensation plans to reward the best workers. Money motivates most employees because it caters to their basic needs, while others view it as a measure of worth to the business. As a result, there should be competitive payment that is based on industry rates, and rewarding exemplary work can be beneficial. There are monetary rewards, such as raises, commissions, performance bonuses, and profit sharing, but other valuable items can count as compensation: vacations, gift vouchers, and any gifts that are not monetary [16].

The report highlights that redesigning jobs is an effective method for businesses to motivate employees. An employee can experience burnout by doing the same routines, so create new and exciting experiences for them. Doing so will motivate employees and will improve productivity. Redesigning jobs can entail the following:

Job enlargement. Reduce monotony by giving more tasks.

Job rotation. Give temporary tasks and different jobs to employees for variety.

Job enrichment. Increase the variety of tasks and give more responsibility to employees. Ensure that any necessary skills required match with the employee's skills.

Creating flexibility. Any modern employee needs personal time, so a nine-to-five workday may not be acceptable to some employees. Give employees some control over their work hours because occasional telecommutes can improve employee morale.

21.5.14 Recommendations for Future Research

The topic on employee motivation and decision-making in the organization is so wide that no single research can exhaust every bit of it. The researcher, therefore, recommends that future research should revolve around the following areas:

Study the significance of improved communication in motivating employees to attain best results. The topic is so important because the employees matter a lot in influencing the productivity of the workforce, as well as the profitability of the entire entity. Also, future research should attempt to understand whether adding more responsibilities to employees as a way of challenging staff to work hard effectively achieves its purpose. Workers can feel included and important to the entire organization, which would inspire them to self-actualize for a higher position. With future research, implications can be resolved by having a reward system in a business of any size.

21.5.15 Limitations of the Study

The first limitation that the researcher experienced relates to ensuring strict compliance with the school rules and regulations for doing research. The research hugely depended on secondary data from the Internet and other sources that did not have authors attached to them. Therefore, identifying and acknowledging the authors to these materials was challenging. However, the researcher tried to adhere to the laws and rules of copyrighting by citing all documents and materials that were used in completing the project. Additionally, finding study and reference material did not constitute a major challenge because the teacher had taught it several times in class.

The other limitation encountered by the researcher was to try and narrow down the research topic to come up with a researchable topic. However, the lecturer in charge of scientific researches came by to assist. Therefore, making the topic moderately specific and general makes it easy for the researcher to collect data and analyze it during the study.

21.6 Conclusions of Research

The study has sought to understand the implications of decision-making by the manager towards the improvement of productivity in the execution of a project. Projects are temporary undertakings by an organization to meet a particular goal or function. The research acknowledges the important role that a manager plays in ensuring that the project becomes a success. However, a manager does not work alone in ensuring that the project is realized, as he or she works through other human resources who, through effective motivation, commit to the realization of the project's specific objectives.

The paper has identified the various ways that managers of a project can motivate and inspire teamwork, while ensuring that the organization realizes its core and primary undertakings. For instance, the recognition and rewarding of exemplary performers has been proven to intrinsically motivate an employee to try his or her best to receive a reward. The good performance will emanate from the feeling of satisfaction that the worker derives from the reward obtained. Additionally, incorporating the employees in the process of making decisions that impact the whole organization makes them valued as a part and parcel of the entity. It is the sense and feeling of being valued that will motivate one to work harder to attain better results.

The researcher has also found out that job redesign, enrichment, job rotation, and creating flexibility at the organizational level help to enrich the goodness of the job, which facilitate job satisfaction. In fact, in the words of this project, a satisfied employee is a performing employee. The worker perceives satisfaction when he or she finds the organization recognizing and acknowledging her or his existence in the organization, as well as when the input that the staff member puts in the organization is valued. Also, there needs to be a compensation plan to reward the best employees in an organization. Money can only do so much, so competitive payment, other monetary rewards, and nonmonetary rewards (vacations, gift vouchers, etc.) can help to motivate them.

A project manager is meant to make great products, so employees need to feel pride in their work, too. They should not feel forced but rather motivated to do their jobs. Businesses have a lot to gain from creating an optimal workforce. These benefits can only be realized through embracing motivation in the organization, and if the managers take a leadership role in the company. As leaders, managers can positively create a sense of recognition for the employees, which will inspire them to work hard towards attaining objectives.

The report has also pointed out that the management of a company like Apple hires excellent people, gives them a portion of the business, and makes them run it. Thus, the staff is allowed to make good and informed decisions, even though the decisions can fail the unit managed by the new employees. The management does not, in any way, bush the workers. Instead, it recognizes the failure as a form of learning for the staff. At Apple, the management believes that employees can learn effectively from their mistakes, so as to plan and formulate the best decisions. In order to attain this level, the managers and management at large ensures that the new employees understand every aspect regarding the business structure. When the employees understand everything about the business, they will take their work seriously because they feel like a part of the company.

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Chapter 22
Role and Impact of Leadership in Project Environments and How to Effectively Use Leadership in Project Environments

Brian J. Galli

22.1 Introduction

Leadership is a key concept that has been used in the past decades. We can select the best definition of leadership and leadership styles by comparing the previous studies. Due to the variety of people, personalities, and types of industries, too many styles of leadership were introduced. Also, each style has its own definition and specifications. However, with high volume of different leadership styles, the overlaps between them could be figured out. This study is aimed to examine the overlaps and the factors that affect the role of leadership in project environment. In our research, we created three essential tables that categorize and describe the leadership styles, as well as identify the factors of the leadership styles. Analyzing the three tables led us to provide the most effective factor that impacts the role of leadership in project environment.

The leadership concept has been studied extensively over the past few decades. Yahaya and Ebrahim [1] find that an organization can be productive, profitable, and competitive through effective leadership. The main attributes of effective leadership during the last three decades were summarized by five attributes as explained by Gandolfi and Stone [2]. The first attribute is to model the way that deals with how the leader's personality affects the behavior of followers to reach the desired goal. The second is to inspire the shared vision, which shows the cross context between followers and leaders to understand the organization values [3]. The third is to challenge the process, which deals with identifying the reasons behind doing the tasks. The fourth is to enable people to act by giving authority to followers to make

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decisions [4, 5]. The last one is to encourage the heart by showing care and celebrating the achievement of goals [5, 6].

As stated by Silva [7], leadership was referred to personal quality for many centuries. Later on, in the nineteenth century, it was referred to as a leader who has the authority and influence with charisma, wisdom, intelligence, as well as political skills. In recent years, researchers have considered the leadership styles as important factors that influence how people function in an organization and in organization, predict performance [1, 8].

The objective of this research paper is to identify the role and impact of leadership in project environments, as well as to examine the effectiveness of leadership among organizations. Furthermore, this paper has a primary contribution to find the gaps in which leadership style has the most effective impact toward the organization's success [9, 10]. All of the recent researches focused on categorizing the leadership styles, identifying new leadership styles, and finding the overlap between them. Hussain and Hassan [11] claimed that selecting a specific leadership style is significantly difficult due to the overlapping between various leadership styles. However, this study examines the overlaps and the factors that impact the effectiveness of the leadership styles in the organization performance [12, 13].

This study's remaining sections are organized in the following way. Section 22.2 explains the literature review in detail. Section 22.3 features information on the methodology, hypotheses, and focus of the research. Section 22.4 explains the information behind the results. Section 22.5 addresses the result, while Sect. 22.6 features the summary and conclusion.

22.1.1 Research Gap

Available research discusses different forms of leadership. However, no existing literature fills the gap on literature regarding the right leadership models for project management environments. That is the gap this study seeks to fill.

22.1.2 Research Objective

Proper leadership is an essential aspect of project management and performance. Thus, it must be studied as such in this study. This study focuses on assessing the elements of proper leadership within project management and performance scenarios in order to identify the best leadership style. Questions frequently asked about leadership are addressed, including how to make the best use of leadership to meet project management and performance objectives.

22.1.3 Originality

We aim to further develop current literature on suitable leadership techniques in project environments. Also, we further develop the similarities and differences that the leadership models have. We then include data that is derived from various studies to assess the hypothesis of this study. In this study, we took into consideration different perspectives on the subject to propose new ideas. This study employs a design-science-investigate strategy and creates a suitable assessment model of leadership types to examine the hypotheses and answer them. As mentioned, there is valuable contribution from this research for project management and operations management. Practicing proper leadership skills, as demonstrated throughout this paper, will help organizations and teams reach success and project goals.

22.1.4 Organizational and Managerial Contribution and Relevance

Through a unified framework, this study contributes much about leadership in the field of project management. Using preexisting research, this study fills the research void and benefits those in the profession to make practical changes to their work environments. This study not only contributes to preexisting literature for research purposes but also offers new ideas for organizations to apply in proper leadership. As a result, a practitioner can find aid in understanding leadership in real-world environments, which can help to apply more effective strategies.

22.1.5 Contribution to the Field and Profession of Industrial Engineering

This study also contributes to Industrial Engineering (IE) research and practice. This is because it teaches engineers ways to improve the work process and economize on productivity-hindering resources. Once the engineer's productivity improves, more benefits will arise in the organization and project success. Aside from a practitioner's perspective, this research benefits the IE research field because it teaches readers of all types the most fundamental things to know about leadership in project environments.

Lastly, we organized the study to be easy to read and understand. The following section is an advanced outline of existing research on project environments and leadership models. Next, Sect. 22.3 addresses the research methodology. The fourth section examines the research that supports the findings. The final section features the findings' implications, suggestions for future research, research limitations, and general conclusions.

22.2 Literature Review

22.2.1 Leadership Definition

Silva [7] conducted a study to develop a leadership definition, which focuses on process, influence, context, people, and goals. In Silva's [7] study, he explained the leadership process as a series of actions that lead to a specific result. Furthermore, he describes the leadership influence as having an effect between leader and followers. Also, he defines the context as the course of determined events that affect the leadership process. He explains that people are followers who accept someone as a leader in a certain context. Lastly, he defines the goals as key indicators to followers that the leader is working on their behalf toward the shared goals.

22.2.2 Principles and Dimensions of Leadership

According to Gandolfi and Stone [2], there are two guiding principles for leadership, which are that everyone has a certain ability to create leadership relations, and leadership is something that is made, but one is not born with. In terms of the dimensions of leadership, Kesting et al. [14] pointed out that there are four generic dimensions of leadership. They were explained as follows:

1. People: the existence of leader and followers are part of the leadership concept.
2. Means: the main objective is to lead followers and influence them to do tasks by coaching or empowering.
3. Effects: the leader should be able to influence the follower by enhancing enthusiasm and commitment.
4. Goals: the leader's main objective is to give directions to achieve specific or generally desired goals.

22.2.3 Leadership Styles

As stated by Gandolfi and Stone [2], leadership style is the intentional approach, where the leader can influence a team in an organization to enhance their understanding in the future state, which differs from the current state. Moreover, leadership styles are essential because they express and represent several ways to practice the leadership concept among leaders and followers [14]. Due to the importance and variance of leadership styles, a leader must have the ability to alternate across the leadership styles to effectively handle any situation that might be faced [15, 16].

In the literature review, scholars have focused on defining the leadership styles and categorizing them. Table 22.1 shows the leadership style categorizations in

Table 22.1 Leaderships styles categorizations and description

Leaderships styles	Description	Centric
Situational leadership	Based on the organization's current situation, organization seeks to have the right leadership skill set, which is affected by follower readiness	Follower centric
Contingency leadership	Based on the context of an organization in which followers have influence on, and the effectiveness of the leader's style will be determined	Follower centric
Transactional leadership	Based on organization goals, leader directed the followers to meet the goals by focusing on transactions	Follower centric
The leader member exchange (LMX)	Based on working dynamics, the effectiveness of the working relationship between leader and follower is directly related to the work itself	Follower centric and leader centric
Transformational leadership	Based on how the leader could inspire or motivate followers toward achieving the vision of the organization	Follower centric and leader centric
Servant leadership	Based on how the leader devotes his or her effort to be a servant for the followers	Follower centric
Autocratic leadership	Based on how the leader makes decisions and sets expectations regarding the task assigned to followers	Leader centric
Democratic leadership	Based on decision-making that could be taken by leaders and followers to achieve the overall goals	Leader centric
Laissez-faire leadership	Based on how followers perform the tasks and make decisions	Leader centric
Coercive leadership	Based on command and control method, where compliance is needed	Follower centric and leader centric
Authoritative leadership	Based on who the leader directs among the followers to achieve common goals	Follower centric and leader centric

terms of leader centric, or follower centric. Their main objectives are based on a study conducted by Gandolfi and Stone [2].

Some other leadership styles are equally important to be mentioned and described. Anderson and Sun [17] described certain leadership styles as shown in Table 22.2.

22.2.4 Leadership Performance

Leadership performance is a key factor that affects the success or failure of several types of projects [18]. In order to know the impact of leadership performance, we need to know how important the leadership is. The importance of leadership was described by Nixon et al. [18] as a mandatory requirement that leads to project excellence, determinant to project culture, and an approach to drive people for

Table 22.2 Summarized description of certain leadership styles

Leadership styles	Summarized description
Charismatic leadership	The leader's capacity to motivate followers into fully applying themselves to fulfill the leader's vision or the business' vision
Initiating structure and consideration	Initiating structure is related to the role and how the leader manages the tasks, while initiating consideration is related to people and how the leader creates a relationship with followers
Ideological leadership	The main emphasis is related to personal values and maintaining standards, as well as commitment to standards
Pragmatic leadership	It deals with daily problems and identifies the most cost-effective approach that meets the functional needs
Authentic leadership	A particular pattern of the leader to create positive psychological abilities and ethical surrounding in the workplace
Ethical leadership	The display of normal behavior among personal actions and inter-personal relationship toward followers
Spiritual leadership	It includes behaviors, attitudes, and values that are essential in motivating people toward spiritual survival
Integrative public leadership	It deals with creating groups and organizations together that are diverse in nature to solve complex public issues and to achieve the desired goals
Shared or distributed leadership	It distributes the influence of leadership among the team members based on their experience to achieve the shared goals

change. Leadership performance is also related to the leadership competence, which should be considered when assigning a leader to a project [16, 19].

22.2.5 Research Gap

Even though there were a considerable number of studies in the leadership styles, no interest was taken into account to examine the overlap between the leadership styles in terms of their factors and how the factors impact the role of the leadership in project environment. Therefore, this study aimed to discuss the most effective factors of various leadership styles that help the project environment to reduce the negative impacts and to maximize the positive impacts of such factors.

22.3 Research Methodology

Our methodology analyzes scientific articles about leadership. Also, our search was limited to peer-reviewed articles because they are considered more reliable. This research was meant to discover the factors that affect leadership efficiency within project environments. Thus, we researched the overlaps between different leadership styles, as they all have different influences on project management environments.

22.3.1 Search Criteria

We employed three criteria to identify relevant papers. First was type of document. We only sought scientific, peer-reviewed articles. Second was the time period, thus preferring articles published between 2010 and 2017. This way, they were more relevant to changing times and environments. Third was topic. The search was related to different leadership styles. The search was expedited by looking for the term leadership in titles, abstracts, and keywords.

22.3.2 Content-Based Search

During this stage, we searched for many aspects within leadership to get a better understanding of the previous and current state of different leadership styles. Some identified key themes included leadership styles, categorization, factors, and overlap between leadership styles.

22.3.3 Evaluate Search

We identified papers from reliable sources, including databases like ProQuest, ABI/Inform Global, and Science Direct. We evaluated identified papers by examining their titles, abstracts, and conclusions to make sure they shared themes relevant to this study. Duplication or irrelevant helped eliminate papers from this search phase. By the end of the process, we selected a total of 15 papers.

22.4 Results

Dartey-Baah [15] conducted a study that shows the relations between leadership and the desired outcomes of an organization as employee motivation, organizational culture, employee satisfaction, team performance, employee performance, and organizational performance. In order to identify the most effective factors that impact the leadership styles, we need to identify the overlap between leadership styles and its impact on the project environment.

The results section was divided into two parts. The first is regarding the factors that affect the leadership styles, while the second is related to the overlaps between the leadership styles.

22.4.1 Factors Affect Leadership Styles

Table 22.3 shows the factors that affect some of the leadership styles. In this section, we selected the most common leadership styles to be the foundation of our study.

Table 22.3 Important factors of leadership styles

Leaderships styles	Factors	Source
Servant leadership	• Altruistic calling: a leader's desire to make a positive change to followers' lives • Emotional healing: the ability to understand the needs of followers and to listen to them • Wisdom: the ability to make right decision and to understand the future aspect • Persuasive mapping: the ability to be reasonable and productive to persuade followers • Organizational stewardship: the capability to create a community in an organization	Muthia and Krishnan [20]
Transformational leadership	• Idealized influence: the ability to inspire appreciation and faith, as well as respect among followers • Inspirational motivation: the ability to make the followers responsible and ready to work toward the responsibilities • Intellectual stimulation: the ability to create a challenging environment and find opportunities to enhance the follower's analytical thinking • Individualized consideration: the ability to give individual attention to a follower to motivate the follower	Muthia and Krishnan [20]
Charismatic leadership	• Sensitivity to constraints, threats, and opportunities • Creating an attractive strategic vision • Handling personal risks • Displaying uncommon behavior • Sensitivity to follower needs	Anderson and Sun [17]
Transactional leadership	• Team performance • Ethics of justice • Employee creativity	Anderson and Sun [17]
Pragmatic leadership	• Follower self-interest • Social fabric	Anderson and Sun [17]
Authentic leadership	• Aspect of self-awareness • Relational transparency • Balanced processing • Internalized moral aspects	Anderson and Sun [17]
Ethical leadership	• Humane orientation • Justice orientation • Sustainability orientation • Moderation orientation	Anderson and Sun [17]
Integrative public leadership	• Integrative thinking • Integrative behaviors • Integrative leadership resources • Integrative structures and processes	Anderson and Sun [17]

They are servant leadership, transformational leadership, charismatic leadership, transactional leadership, pragmatic leadership, authentic leadership, ethical leadership, and integrative public leadership styles.

From Table 22.3, we examined all the factors for each leadership style and compared them to find the overlapping between leadership styles.

22.4.2 Overlapping Between Leadership Styles

22.4.2.1 Charismatic and Transformational Leadership

There are two overlaps between charismatic and transformational leadership styles.

1. In the charismatic leadership style, sensitivity to follower needs is a factor. Similarly, transformational leadership style has one factor that deals with individualized consideration, which addresses the followers' needs.
2. In charismatic leadership style, creating an attractive strategic vision is a factor. In the same manner, transformational leadership style has an inspirational motivation factor, which deals with how the leader addresses a vision that inspires followers.

22.4.2.2 Transactional, Servant, and Ethical Leadership

Transactional, servant, and ethical leadership styles have only one overlap. Ethics of justice is a factor for transactional leadership style. Wisdom is a factor for servant leadership style. Lastly, justice orientation is a factor for ethical leadership styles.

22.4.2.3 Authentic and Ethical Leadership

There is only one overlap between authentic and ethical leaderships. Internalized moral perspective, which deals with moral standards and personal values, is a factor for authentic leadership style. Likewise, ethical leadership style has two factors that are related to the moral perspective. The first one is human oriented factor, which deals with dignity and respect. The second one is justice-oriented factor, which deal with fairness.

22.4.2.4 Pragmatic and Ethical Leadership

The existing overlap between pragmatic and ethical leaderships falls into one factor. In pragmatic leadership style, social fabric, which deals with stakeholders and social parties, is considered as a factor. Correspondingly, ethical leadership style deals with sustainability orientation that focuses on the welfare of society.

22.4.2.5 Charismatic and Authentic Leadership

Dealing with challenges or risks is a common factor in both charismatic and authentic leaderships. In charismatic leadership style, handling personal risks is considered a factor. In the same way, authentic leadership style has the balanced processing factor that is related to challenges.

22.5 Discussion

As stated by Rowold and Borgmann [21], the validity of leadership styles is dependent on their effective factors. As a result, the overlaps, in terms of leadership style factors mentioned in this study, would help us to figure out the most effective factors that impact the success of leadership in project environment.

22.5.1 Most Effective Factors of Leadership Styles

According to our results, we have established the final list of the most effective factors of leadership styles that support success in the project environment. The final list is explained as follows:

1. Sensitivity to follower needs: the leader should support the followers to be committed to an organization's mission and to create a trust that will lead to a better follower performance [22, 23].
2. Creating an attractive strategic vision: leaders have the ability to create a meaningful organizational vision that enhances the organization to achieve the desired goal [23].
3. Ethics of justice: wisdom and justice: Washington et al. [24] performed a study that shows that the leader's success in behaving ethically by involving certain interactions that have fairness and honesty with followers will lead to a successful leadership.
4. Moral perspectives: the leader should have a self-regulation with high values and moral standards [17].
5. Social fabric: the leader should be knowledgeable of all parties who are considered as stakeholders for the problem, solution, technical, and economic issues [17]. Furthermore, Huhtala et al. [25] claimed that the leadership behavior should have a prosocial behavior to make it a success.
6. Dealing with challenges or risks: the leader should have the ability to analyze data and to look for different views to end up with a solution that deals with challenges and risks [17].
7. Motivating followers: the leader should have the ability to motivate followers and to make them responsible for working toward the responsibilities [20].

22.5.2 Successful Leadership

Nixon et al. [18] claimed that a successful leadership is related to convincing and driving people to change, having the ability to think analytically and to solve problems, encouraging people to work as a team, and accomplishing the desired goals. Furthermore, leadership has been considered as a factor that enhances the success of an organization for a long time. In recent years, leadership was also considered a factor in project management environment [8, 12, 19]. Even the cultural aspect took a place toward the success of leadership. According to Jogulu [26], Asian culture would work more effectively in transformational leadership style, while Caucasian culture would not. In addition, we also find that culture has essential factors that affect the project environment.

22.5.3 Organizational Implications

Studying different leadership styles is beneficial to project environments, where they can develop the proper skills and effective teams around such leadership adoption. This study's results show how important it is to apply the proper leadership style in a project environment. The proper training and leadership techniques can improve a business' performance and effectiveness. It can also help to identify any issues within teams and the overall performance. Adopting the appropriate leadership style must be addressed and stressed more in organizations to help the organization benefit and profit in the long run. Too many leaders focus on finances and profit, which helps the short-term growth, but doesn't provide for long-standing success. Thus, this research presents new ideas for leaders to adopt in order to pursue long-term growth and success.

22.5.4 Managerial and Team Implications

This study provides an outline for project and organizational performance and effectiveness. Adopting the appropriate leadership style can expand on leaders mentoring and managerial constructs so that all departments and teams can better pinpoint internal weaknesses. This helps measure improvements to overall performance and effectiveness. The benefits related to proper leadership will trickle down into team environments because teams will have a better understanding and ability to recognize things lacking in their performance and efficiency. Proper leadership will help individuals and teams troubleshoot problems to achieve project and organizational goals.

This study also develops a more accessible and understandable training program geared towards project and organizational performance and effectiveness. Applying this to project teams and leadership, as well as organizational leadership will see benefits across the board. Such training will better equip teams and leaders with the proper tools to improve team and organizational performance and effectiveness. Organizational leadership can learn to adapt to suitable leadership methods that will help and improve team and project performances.

22.5.5 Implications and Applications to Fields of Project Management and Engineering Management

Understanding proper leadership styles is also beneficial to engineers and technical professionals. Engineers work in project environments and also need a better grasp on business management to provide the most economically viable solutions. Seeing management and engineering on the same playing field provides benefits to not only the engineering side of an organization but also the management side. A vital aspect of the modern IE/EM profession and research field includes proper leadership styles in project management. Therefore, knowledge about this subject must be developed and shared in the profession in order to provide maximum benefit to engineers and businesses in general.

Any business field that develops products and services to remain successful is in need of project management. Stakeholders, such as system engineers, project managers, and other engineering experts, will gain important information from this research to then apply these findings to real-world project management scenarios. In the end, this study's findings will provide assistance for stakeholders to not only make best use of system engineering roles but also to make the best use of the role of project management. This will guarantee that projects will be successfully implemented in businesses.

22.6 Conclusion

After careful analysis of the leadership styles, we were able to find the most effective factors of leadership styles that impact the project environment. Moreover, we compared the leadership styles and found the overlap between some of them, which helped us toward finding the most effective factors. In summary, the most effective factors of leadership styles are sensitivity to followers' needs, creating an attractive strategic vision, ethics of justice, wisdom, moral perspectives, social fabrics, dealing with challenges or risks, motivating followers, and culture.

22.6.1 Limitations

The results of this study were limited. First, there was a small sample size and key factors. This leads to potentially biased results and can be avoided by employing a larger sample size. Another limitation was focus on key factors in a project environment rather than all types of managerial settings and businesses. As a result, applying these findings to other areas may be more challenging, if not prohibited. Another limitation is that the paper is conceptual and would only support implementation in private and nonprivate organizations to actually determine which are the most effective factors in leadership styles. The final limitation is that the literature review was based on only peer-reviewed articles during a long time frame from 2010 to 2017.

22.6.2 Future Research

Some future research can be conducted on leadership style relationships in other industries and managerial settings than just project environments. The influence of each type of setting on leadership styles can be examined. Analysis of different perspectives, such as cultural, organizational, or strategic, on leadership styles may also be an avenue for future research. This would provide knowledge on how such a relationship is affected by culture, strategy, human resources, and operations.

More research can be conducted to analyze the most effective factors of leadership styles in profit and nonprofit organizations, as well as educational sectors. Finally, researchers should identify how leaders can transform between differing leadership styles to effectively meet project and organizational goals.

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Chapter 23
The True Pillars of Quality Management: How to View Them

Brian J. Galli

23.1 Introduction

An excellent quality management system is vital for a manufacturing organization to enhance its competitiveness. Over the years, TQM (Total Quality Management) has become a crucial tool for the sustained growth and support of manufacturing organizations. In an increasingly competitive business environment however, developing the appropriate foundation for TQM implementation continues to challenge many organizations. A comprehensive framework for TQM implementation engages several essential pillars and associative factors. This research examines and evaluates the true pillars of quality management: creation of quality management environment, teamwork, quality control tools and techniques, supplier relationships, and customer focus. Findings suggest that factors associated with these pillars are significantly evidenced in the studied organizations.

"Quality" is identified as an essential business driver in today's global market. For decades, Total Quality Management (TQM) has been receiving global attention from both practitioners and researchers. Many manufacturing firms implement TQM principles with the aim of delivering high-quality products to their customers. Some are successful, while others are not. Quality management is principally concerned with the delivery of high-quality products from manufacturers. TQM is defined as both a philosophy and as a set of guiding principles that represent the foundation of a continuously improving organization [1].

Total quality management is the science of managing the whole to achieve perfection in product or service. The nature of TQM is uncertain, and there is little agreement on what defines it. However, researchers and practitioners identify TQM

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as both a philosophy and a principle that represents the foundation of a continuously improving organization. TQM enhances the old methods of doing business, as it is mostly common sense that refers to the global efforts for businesses to achieve quality. Furthermore, TQM is a philosophy of quality that includes all those involved in the business to attain quality [2, 3].

Process improvement is a fundamental characteristic of TQM programs. It starts with process analysis and holds the intention of reducing or eliminating variance. Typically, in a manufacturing system, there are five types of problems: compliance, unstructured, efficiency, process design, and product design [4]. Compliance, unstructured, and efficiency are all performance-related problems, while process and product design are design obstacles. To properly address these problems, a business must apply the system of "plan do study act" cycle. This is a resourceful method for continuous process development, as process improvement is essential to successfully implement TQM [4, 5].

Employee involvement is a process for approving members of organizations to make decisions and solve problems appropriate to their levels in the organization. Employee engagement becomes significant when a strategic connection is established through leadership, systems, and processes. Each is supplemented, moreover, with the necessary tools. Thus, all employees need to be motivated and satisfied when involved in the TQM process. For employee motivation, recognition and rewards involve the business' public support of an employee's positive contributions. To get the optimal benefit from a quality program, employee empowerment is necessary [5, 6].

Employee empowerment includes a degree of freedom for cross-departmental and team works, employee freedom in decision making, employee communication with customers, and employee suggestion systems in strategy formulations. An employee is held responsible for accomplishing a whole task, as he becomes the process owner [4]. Employee empowerment is considered an integral part of any successful quality improvement process, and helps employees make decisions concerning their work and environment. This method also encourages people to apply the most appropriate tools and techniques in their work. The term "training" refers to the possession of knowledge, skills, and competencies, because of the teaching of vocational or functional skills, and knowledge that correlates to specific, useful competencies. Training has specific goals of improving one's ability, capacity, and performance. Training and education are necessary to teach the TQM principles that require continual change in individual behaviors and attitudes to help establish an organization's culture [1, 7].

23.1.1 Research Gap

Current literature does not discuss how to implement the proper foundation for Total Quality Management (TQM) by focusing on the essential pillars of quality management. This research attempts to cover that gap to benefit organizations and overall project management.

23.1.2 Research Objective

This study aims to assess the pillars of TQM to properly implement it into an organization. By looking at the similarities and differences, one can learn the best ways to utilize TQM for organizational success. Commonly asked questions are further addressed to facilitate the learning of readers. A final objective of this research is for it to be an avenue for future research to be conducted.

23.1.3 Originality

Data is collected from existing research to address the hypothesis of this research and the questions raised therein. Other perspectives are further considered to suggest new solutions to integrating TQM into a business environment. A design-science-investigate strategy is employed to identify the practical and hypothetical applications of this study's factors. The study then suggests a suitable model for implementing TQM. Results of the study are further explained with suggestions for future research and limitations on the current research.

This paper contributes significantly to existing literature and the profession. The advantages and disadvantages of TQM are discussed, as well as problems that may arise in the real world based on how TQM and its pillars are implemented. Because practicing with TQM is practical and crucial for business organizations, this study is very valuable in both theory and practice.

23.1.4 Organizational and Managerial Contribution and Relevance

This research will benefit organizations and management to better understand the strengths and weaknesses of the pillars of TQM and how to properly implement it to reap success and effectiveness. Further, this research suggests new ideas for researchers in different areas of a business to study and apply in the future. Most importantly, practitioners can benefit from understanding TQM more properly through this research and therefore apply their findings to real-world scenarios.

23.1.5 Contribution to the Field and Profession of Industrial Engineering

This study also contributes to the Industrial Engineering (IE) profession and research fields. Engineers will learn how to better use their resources effectively to be more productive and beneficial to the overall organization. The easy-to-understand vocabulary makes this an easy read for any reader to learn about the subject and then potentially apply their learning to real-world scenarios.

Finally, this paper is strategically organized to facilitate ease of learning by any reader. The second section presents a high-level literature review of the current literature in this field of research. The third section presents the research methodology utilized to execute the research study, while section four presents the findings from the study and analysis. The final section outlines the implications of these findings to the practitioner, suggestions for future research, limitations of the research, and general conclusions.

23.2 Literature Review

According to Islam and Anwarul [1], most companies provide products that meet the requirements of customers and staff, including management. Companies should always try to attain the highest quality. Quality management based on customers' wants and expectations is crucial. With customer satisfaction over products or services, the organization can probably make them partners, too. There are numerous businesses that are trying to provide customers with all designed vital processes, but with required value and high-quality.

Quality is a marketing tool for corporations who understand the benefits associated with satisfactory performance in a market and the efficiencies of production and distribution processes and trade. Marketing departments in small or medium-sized companies are directly responsible for implementing the quality policy. It is a management system where the most important thing is not the interface of the process but rather, the understanding of business management, planning tools based on research, objectives, visions, management, control tools based on the evaluation of deviations, and proposal of risk management measures. The fact is that quality management in a hypercompetitive environment, where supply surpasses demand, is tightly interconnected with the highest level of customer relationship management (CRM). Advanced quality management textbooks have introduced terms like CRMQ: Customer Relationship Management and Quality [2, 3, 8].

Al-Bourini et al. [6] attempt to identify the effect of the organizational culture on total quality management. Of the most striking results is a statistically significant effect of the organizational culture on overall quality management in insurance companies. The authors also explain substantial differences at the significance level of the impact of corporate culture on TQM in insurance companies attributed to the difference of the occupational variables. The study recommends increasing the interest in improving the availability levels of the organizational culture dimensions. Availability levels place a focus on the relatively low-level sizes, and the necessity to consider realizing coherence among these dimensions regarding the closeness of the availability levels and lessening the deviations among these aspects, as well as the elements of one dimension due to the integrative nature of them. The study further recommends assimilating the organizational culture as a central concept by the managerial leadership, being an essential foundation, upon which the success or failure of applying the TQM depends.

Organizational culture or organizational values and characteristics were neither studied nor practiced before the second half of the twentieth century. The 1970s showed an increasing interest in these areas; and attention culminated in the 1990s. Additionally, the concentration of writers and researchers in the field of management and organizational behavior improved regarding organizational culture. They dealt with its many aspects and recognized it as one of the crucial factors for success of organizations and the effectiveness of their management. Moreover, today's organizations are in real need of change and achieving elevated levels of efficiency and performance to enable them to continue, compete, excel, and adjust in conformity with the ambient environmental variables [6].

Organizational culture occupies a prominent status in managerial performance and development, an area deemed as essential in the modern age. All organizations and departments of both the public and private sectors need to face the accelerating events of the world as connected by the latest communication methods. In this regard, some conclusions can be made: the prevailing organizational culture in insurance companies tends to be of the bureaucracy style regarding centrality, weakness of delegation levels, low care in motivation and promotion of creative people. Also, there is a lack of development and sharing of the decision-making process, care in quality and productivity, and low interest in discussing work results. The highest percentage is on the field of focusing on the administrative and technological needs for competitiveness. These companies do not adequately focus on improving the processes, since there is no plan to shorten the times devoted to completing the transactions [6].

Munizu [9] explains that quality has become one of the essential factors in global competition. Increasing customer demand for greater quality of products in the marketplace encourages many companies to provide better quality. Many businesses invest in accommodating and implementing total quality management (TQM) practices to create and deliver products or services, which are compatible with customers' needs and requirements by better, cheaper, faster, safer, and more natural processing than that of their competitors. It also incorporates the participation of all employees under top management leadership. Therefore, manufacturing companies should be the focus of quality.

Attention to quality generates a positive impact on business performance through both the impact on production costs and earnings. Corporate performance is not described in detail by academics, and the traditional approach to performance measurement, using solely financial performance measure is flawed. Many earlier studies measured organizational performance using both financial and market criteria, including return on investment (ROI), market share, the profit margin on sales, growth of ROI, growth of sales, and growth of market share. TQM practices have a positive and important effect towards organizational performance and competitive advantage. Organizational performance positively influences competitive advantage, so TQM practices do not affect organizational performance as much as competitive advantage. TQM practices best explain bettering organizational performance through competitive advantage dimensions (delivery, price, time to market, and innovation). Thus, the best performance is contingent on a better competitive advantage [9].

Romeo et al. [10] describe effective quality management in the design and construction of building projects as a crucial factor in the successful management of building projects that ensure the accomplishment of a client's requirements. In the construction industry, quality management deals with quality control, assurance, and improvements. Over the last 10 years, there has been limited client satisfaction from built facilities, as there has been poor quality performance that extended from perennial problems: time and cost over-run [6].

The authors further explain three key findings that reflect the research subject. The first finding is how construction industries have limited awareness of Quality Function Deployment (QFD). Research respondents attribute this to insufficient training and retraining of employees, insufficient management, and not having suitable measures for self-improvement, especially for building professionals. Secondly, there was a finding about how effective QFD is in design and build projects, which is most evident through fostering of mutual relationships between the construction company and its clients, identifying client requirements, and systematically converting these requirements to technical objectives. The last finding is how design and build projects yield a low level of satisfaction from clients, as respondents attribute this to compromising the customer's voice, as well as poor design [11].

It appears that most companies lack the technical means to convert client requirements to expect and new objectives. This research analyzed reactions from 22 respondents, and only five were satisfied with the finished products [9]. An interesting finding is that these five satisfied clients contracted their projects to those companies aware of QFD and apply it regularly to design and build projects. Evidently, these research findings illustrate that QFD facilitates identifying, prioritizing, and satisfying customer requirements. Also, the findings show that how QFD is perceived is not the same among all building professionals. For construction companies, twenty percent (20%) of the respondents who knew of Quality Function Deployment recognized its strengths in the following areas:

- Identification and Prioritization of Customer Requirements. In design and construction, the client's voice (VOC) is always considered, but thirty-five percent (35%) of the respondents argue that clients usually cannot understand or state their desires. Proper documentation of VOC and using matrices to separate requirements makes it easier to identify, improve, and prioritize client requirements.
- Fostering a positive relationship for clients and construction companies. Respondents attribute a positive relationship between clients and companies throughout construction and completion to applying QFD. Respondents find that it encourages both parties to hold regular meetings and discussions, which helps the companies to understand client requirements. Furthermore, it helps the design team to have an effectual client brief.

- Increased customer satisfaction. According to the respondents, 25% of them focus on their customer satisfaction. To help in this process, QFD systematically applies techniques and technologies to facilitate these processes.
- Applying QFD facilitated communication, interrelatedness, and the exchange of knowledge amongst QFD team members. The majority of respondents see QFD as a way to learn, as it includes team members from various lines of work [9].

23.3 Methodology

For the literature review, both a simple search and an organized search were utilized. With the simple search, we found pertinent information about TQM and its pillars, while the organized helped to search databases for helpful information.

23.3.1 Simple Search for Literature Review

Useful essays were found through their keywords within the abstract. We collected any essays that were related to TQM and its pillars. Before the organized search, 15 articles were identified in this step.

23.3.2 Organized Search for Literature Review

The organized search featured three steps. The first was to plan the search, as we found pertinent papers about TQM and its pillars. Secondly, we conceptualized the review and defined new terms that would support the study. At this step, we searched the abstracts for their keywords. Finally, we had to search, evaluate, and select whatever literature was best. To do so, we utilized databases (ABI/Inform Global, ProQuest, and ScienceDirect), so as to evaluate the abstracts, introductions, and conclusions of studies. Anything irrelevant to this study's topic was eliminated, so 80 papers were identified.

Figure 23.1 illustrates the search and selection process.

Figure 23.1 summarizes the three steps. Overall, 18 studies were selected. Thirty-five studies were identified during the selection step. Based on the title, abstract, or duplications, certain studies were not used, and we focused on peer-reviewed articles, academic articles, and literature reviews. During analyses, the selected studies were reduced to be $N = 4$ and $N = 14$, and we evaluated studies to have $N = 18$ articles.

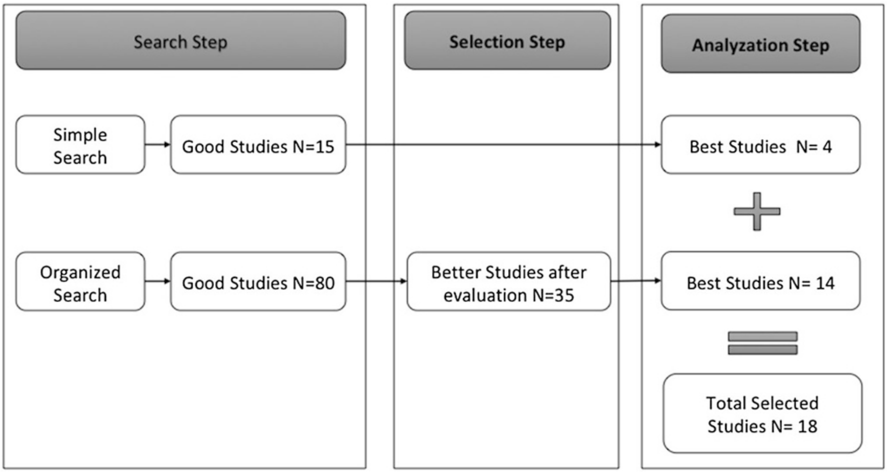

Fig. 23.1 Research approach for literature review

23.4 Findings

The following are the most important pillars of quality management, as described in the literature review.

23.4.1 Creation of Quality Management Environment

Creation of Quality Management (QM) helps create the environment for all employees to seek out quality problems and improve them. The implementation period must feature the environment, as a business must know their vision and goal for implementation. Associations will not start transforming TQM without knowing and developing the quality of its product or service. Therefore, the awareness program for TQM implementation is necessary to create an organization-wide positive environment. At the start, seminars, discussions, or workshops in the organization can have this occur. Afterwards, it can be done with formal training and education programs for essential employees within the TQM implementation teams [1].

23.4.2 Development of Teamwork

For continuous improvement, customers' requirements must remain satisfied. Businesses must be prepared to find information to identify customer requirements, as well as to quickly gain steady feedback on quality levels of its current products or services. Thus, employees must be included during the decision-making process, so as to meet quality levels [12].

Learning and valuing the input of teams is an important component of TQM. The essence of teamwork is the high value connected to collaboration. Collaboration may entail many partnerships and can include nonorganizational members. Solutions conceived of collectively are thought to be better, more creative, and fostering commitment to the outcome. To realize the benefits of collaboration, however, teams must genuinely expedite the participation and involvement of its members, overcome hierarchical power deference, and complete the actual solving of problems. In organizations that do not follow TQM philosophy, managers are often on the hunt for someone to accuse of indicated problems [3].

23.4.3 Practice of Quality Control Tools and Techniques

TQM places responsibility on all employees. When employees identify the correct quality problems, they must apply appropriate tools and methods. To improve product and service quality, Statistical Process Control (SPC) is the best tool. This includes basic techniques like Process flow diagram, Cause-and-effect diagram, Check sheets, Histogram, Control charts, and Scatter diagrams. This tool can be used to control the process as well as improve process capability.

The introduction of the SPC tools to employees is to benefit the executing of TQM. The involvement of SPC tools and the associated techniques for investigating and solving problems can boost TQM implementation. The technique of Failure Mode and Effect Analysis (FMEA) unites technology and personal experience in identifying a product's failure modes, as well as in planning how to eliminate it. Implementing design FMEA establishes main concerns with anticipated failures, miscalculations, and errors from reducing development time and the cost of the manufacturing process [6]. On the other hand, FMEA can recognize potential process failure modes and help establish priorities according to relative impact on internal and external customers. Thus, by implementing FMEA, an organization can reduce potential failures in its product and process, which is one of the targets of TQM implementation.

Within a product manufacturing system, it is important to have good maintenance. By practicing Total Productive Maintenance (TPM), the current plant and equipment will maintain the highest level of productivity, if all areas of the business cooperate. The aim is to eliminate unplanned equipment and plant maintenance. TPM is an extension of the TQM philosophy for maintenance, as well.

23.4.4 Focus on Customer

With TQM, it is recognized that a product is worthless if a customer does not want it, even if it is made well. Thus, the quality of the product is driven by the customer, as customer satisfaction must take priority during the planning processes. Then, it must be maintained all the time. To see continuous improvement, one must monitor and meet customer requirements. Any organization must be prepared to find information to classify any customer requirements [13].

Employee motivation plays a vital role in focusing on customer satisfaction. The motivated employee can perform better than a de-motivated one. Customer expectations are exclusive to a customer, as they are never the same. As a result, the business uses an organized system that identifies and prioritizes customer demands, so that the product or service meets these needs. A business can apply the strategic tool of Quality Function Deployment (QFD) to capture the customer's voice in a series of matrices for analytical purposes. Thus, one can better analyze product/service quality characteristics, costs, reliability, and the use of new concepts and technologies to guarantee that TQM aligns with the customer [6].

23.4.5 Focus on Supplier Relationship

Management must permit adequate time for the purchasing department, so as to find low costs, qualified suppliers, and submitted information. Setting an unrealistic deadline may cause a poor selection that is derived or based on insufficient information about supplier qualifications. Additionally, there must be better communication between purchasing and other departments (i.e. engineering and quality control), when information is needed to evaluate supplier qualifications and their manufacturing processes.

It is not easy to create a stable sense of trust for steady working relationships. Thus, businesses must use the necessary tools, techniques, and systems that will create a suitable relationship with suppliers. For example, one can use systems such as procurement systems, advanced planning and scheduling, and transportation planning systems. Furthermore, standard procurement systems help companies to compare prices and performance capabilities from various suppliers. Any routine transactions during the purchasing process may be mostly automated because the information technology can become available instantaneously [6].

23.4.6 Benchmarking

The systematic method known as benchmarking involves a business measuring its performance alongside top industry practice, which helps with continuous improvement. This is a process of borrowing and applying ideas for a competitive edge. Having to benchmark can come from identifying any digressions from current goals with processes and practices, which can end with achieving any desired improvements in accordance with the best practices [14].

Since benchmarking is not a strategy or business philosophy, one must utilize it for gaining certain benefits. It is efficient with both time and cost, as it involves imitation and adaptation over invention. Thus, to implement TQM, a business can benchmark any adopted strategies and policies [9].

23.4.7 Improvement of Processes

Training production employees and adopting modern technologies, if required, can achieve process improvement. A quality program can begin with process improvement. For many authors, they apply a zero-defect perspective with a quality program, so employees also need a zero-defect mentality [15].

For refinement, activities constantly improve an unbroken process and it improves efficiency. All involved in the organization can apply this strategy to do things more quickly, easily, and with little to no waste. Key factors that yield major improvements in renovation are innovation and technological advancements. For TQM to succeed, both refinement and renovation are vital to process improvement [3].

23.4.8 Involvement of Employees

Allowing employees to be involved in the decision-making process provides the opportunity for process improvement—one of the goals of TQM development. Indeed, it improves quality and increases productivity. Discovering the best factor that stimulates a designing of the reward system can act as a positive feedback to keep TQM active [16].

The employee should be involved in the planning and implementation of the recognition and reward program. Rewards for teams, groups, or individuals can be provided to show that management much appreciates their efforts and contributions. To implement a reward system, performance evaluation is necessary, as it will give information to employees about their performance, promotions, salary increase, counseling, and other purposes related to an employee's future. With empowerment, an environment is created where people are able, confident, and accountable for taking ownership to improve the process and satisfy customer requirements within well-defined boundaries. All members involved in TQM implementation must receive training in group dynamics, communication skills, quality awareness, specific problem-solving techniques (such as SPC and safety), and technical job aspects [9].

According to the framework, the implementation of TQM requires support, which can incorporate eight pillars. All pillars feature vital factors that support TQM, as well as its philosophy and principles. The pillars support each other, so for continuous improvement they create an organizational culture [17].

23.5 Conclusions

23.5.1 Organizational Implications

TQM and its pillars are beneficial to business environments and projects. The findings demonstrate the beneficial use of TQM in general to meet goals and be more efficient. TQM impacts many aspects of an organization, from management to leadership to the supply chain in general. Leadership ought to have proper training to learn how to implement TQM and sustain it. Lack of effective leadership and guidance, on the other hand, may lead to many issues regarding an organization's performance and longevity. Proper training and leadership, however, will help leaders and the organization look forward to the future to improve performance, profits, and cost, rather than focusing on financial aspects in the short term.

23.5.2 Managerial and Team Implications

There were several implications regarding this study. First, it provides new research on TQM and its pillars. Second, it provides an outline on how organizations can implement TQM effectively to obtain long-term success. Organizational leaders can better manage their projects and organizations with this research. Once leaders get a grasp of TQM, the knowledge trickles into the team environments, where they will learn about their weaknesses and correct them to achieve ultimate performance and effectiveness. The final implication of this study is to develop a more accessible training program geared towards project and organizational performance and effectiveness. This training can apply to project teams, project leadership, and organizational leadership. Furthermore, the content can provide training on properly evaluating a team, project, or organization's performance with the use of standard and industry-accepted models and concepts. Such training will better equip teams and leaders with the proper tools to improve team and organizational performance and effectiveness. Teams and leaders can learn how team and organizational performance and effectiveness are important to their environment to achieve optimal performance, effectiveness, and long-term success.

23.5.3 Implications and Applications to Fields of Project Management and Engineering Management

Engineers, as previously mentioned, will benefit from this research to solve problems in the work environment. Management concepts are grounded in science, thus relying on concepts that engineers are already familiar with. Adapting TQM to an engineer's job is demonstrated in this study to help the engineer see how applicable and crucial management skills and knowledge are in the modern marketplace.

Thus, the IE/EM profession and research field are greatly impacted by the TQM pillars and their adoption in any business environment. Proper implementation of TQM proves to be the most efficient way to develop different, successful environments in the IE/EM profession. To remain successful, any business field that develops products and services is in need of project management through TQM and engineers. Stakeholders such as system engineers, project managers, and other engineering experts will gain important information from this research. In the end, this study's findings provide assistance for stakeholders to not only make best use of a system engineering role but also to make the best use of the role of project management. This will guarantee that projects will be successfully implemented in businesses.

23.5.4 Recommendation for Future Research

Future research can be conducted on the relationship of TQM and its pillars in other industries and managerial settings. In these settings or contexts, studying the strength of TQM and these relationships may be valuable. Another avenue of research could be exploring TQM from different perspectives, such as from an organizational, strategic, or cultural point of view. This would shed light into how TQM is viewed based on culture, strategy, human resources, and operations.

23.5.5 Limitation of Study

This study was somewhat limited. First, it was based mostly on self-reported data from selected literature. Further, it was limited to IT, construction, and public administration, which makes it more challenging to apply the findings to other project-oriented organizations. The sample size was somewhat limited, which creates a potential bias in the results. The key factors identified—regarding the TQM pillars—were also only regarded in the project environment, which makes applying these findings to other areas, such as supply chain, operations, and strategic management almost impossible. Thus, the biggest limitation was that these findings are not that applicable to more general or managerial settings.

23.5.6 General Conclusions

The pillars of TQM implementation in manufacturing organizations includes almost all factors of TQM implementation addressed in the literature. Managers of the studied businesses support six out of eight pillars. The fundamental pillars, or "true pillars," are: supplier relationship, the creation of quality management environment, closer customer relationship, development of teamwork, the practice of quality control tools and techniques, and employee involvement. Although two pillars are, namely benchmarking, and the managers give process development less priority, which directly or indirectly are associated with other pillars. Since previous studies have cited these as vital aspects of TQM, the authors want to keep these two pillars as a part of TQM implementation. Nearly every factor is evident within the studied businesses [6].

According to the investigation, the crucial factors are: training employees, long-term contract with suppliers, formal customer feedback, recognition and rewards for employees, and overall employee development. Other factors of the pillars are introducing quality tools and techniques, organizing seminars and symposiums about quality management, creating quality slogans and exhibits in various settings, and having cross-functional teams. Additional factors can be found in the studied organizations, but they have different aspects and significance [3].

In reference to the successful implementation of TQM in manufacturing organizations, one can conclude that the proposed framework is valid. Also, the comprehensive framework is easily applied to practitioners for implementing TQM. Though this study presents a new approach to implement certain aspects, it features some limitations. For example, in this study, it is assumed that all associated factors carry the same importance, which may be nullified in practice. Again, the framework examination has been achieved in the RMG sector only; this can also be done in other sectors of the manufacturing industry to generalize the framework. Thus, there is room for further study in considering the relative importance of the associated factors in the true pillars of quality management.

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Chapter 24
Comparison of Change Management Models: Similarities, Differences, and Which Is Most Effective?

Brian J. Galli

24.1 Introduction

Some people welcome change, while others fear it. People who welcome change concentrate on the great opportunities brought by it, while people who fear change focus on the risks. Currently in society, the change management has been implemented in almost every aspect of all business sectors because the world is a constantly dynamic community, where the opportunities and risks rotate regularly. The key factor in obtaining great opportunities in this constantly changing environment is within proper change management. Many researchers in the literature field have realized this point. Therefore, there exist many theories about change management. This research paper makes a precise comparison among several leading change management models. Through comparison, great similarities and differences are found among these change management models. For example, the Kotter's change model, the ADKAR, and the Lewin's change management model share likenesses on many stages, but there are many. Thus, one cannot conclude model is most effective. Not only do these change management models emphasize different things, but their application circumstances differ as well. From this research, it is found that Kotter's model pays close attention to the implementation of the organizational change from the perspective of the senior leaders. It is much more effective to adopt Kotter's change model when the organizational change starts with the senior management. Moreover, the ADKAR model focuses on the large organization, and Lewin's change management model concentrates on the reduction of the resisting force. Change management can perfectly fit into the IE field.

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In the current market economic system, organizational change management is needed in almost every perspective of the industry and company. Continuous improvement, business reengineering, strategic alliance, adoption of the outsourcing pattern, and merger and acquisition, all belong to the range of organizational change management. Change could be a chance to improve, which constantly happens in each business sector. However, if the change is not being well managed, it might become dangerous and threatening [1]. It was once stated that change is not always in control by organizations. It is widely researched that it is highly significant to seek changes to gain a competitive advantage for the organization. For example, it is accepted that the sustainable development model is being regarded as an effective method to make the company possess the long-term competitive advantage [2, 3]. Additionally, the core conception of the sustainable development model is innovation, which refers to positive changes [4]. Therefore, change management is critical for any business sector. Within change management, the need for changes must be fully communicated and the crisis that might occur during the changes should be entirely evaluated. Some people resist change because they fear the unknown, so change management became extremely important in reducing fear through effective communication [5].

In this paper, a brief comparison among the major change management models in the current literature field will be made, including Lewin's change management model, Kotter's theory, the Prosci ADKAR model, Systematic model (Kast), etc. Among these primary change management models, three of them will be further investigated by exploring their advantages and disadvantages [6]. The hypothesis of this paper is that Lewin's model, Kotter's eight steps model, and the ADKAR model do share some similarities, while their differences make them the most suitable and effective models in different situations, respectively. This research paper will carry out a thorough and comprehensive analysis and evaluation of the five leading change models in the literature field, which might provide some instructive advices to the industry-engineering field about the implementation of the change plan [4].

As to the industry-engineering field, the demand for the change management model is equally high. The traditional industry engineering was being generated along with the occurrence of the mass production. However, mass production eventually cannot produce great economic interest along with the development of the market [7, 8]. The first oil crisis in 1973 marked the end of the era of large-scale business [9]. Since then, the market has stepped into the path of diversification, so the manufacturers are no longer the core of the market. Consequently, change management is becoming more important in the industry-engineering field.

24.1.1 Research Gap

Although there is existing research about change management, this study fills a gap left in that existing research, by examining different change management models. This research further explains when would be the best scenario to use certain models versus others. Thus, the focus of this study is to evaluate the different change management models and suggest which ones different organizations could use, which is a gap in existing literature.

24.1.2 Research Objective

Aside from filling in gaps in existing literature, this study also assesses the similarities and differences between different change management models and how they interact in different environments. The study is structured in such a way as to be an easy read for people of all levels and to understand how to apply the findings to project management, operations, and performance in differing industries. Commonly asked questions will be answered based on evidence found in studying change management models and therefore, this study will act as an avenue for future research in the field.

24.1.3 Originality

This study incorporates data collected from existing research in a uniformed, well-mannered approach. By collecting existing data, this study achieves hypothesis testing. Some perspectives of other researchers were also incorporated to suggest new thoughts and implementations of change management models. This study is organized to outline existing development models. Discoveries, analysis, and suggestions for implementation are further provided. The findings identified illustrate the value of adopting different change management models per different scenarios. The models' strengths and weaknesses are outlined together with implementing them into true-to-life situations. It cannot be stressed enough how valuable these models are, as practicing them is practical and applicable to just about any business. This study illustrates their value in this way.

24.1.4 Organizational and Managerial Contribution and Relevance

The results of this study can relate to different areas of business and benefit those areas to develop and grow further. A deeper understanding of the change management models can help businesses adopt the best one and become more efficient and effective overall. This study also recommends different ideas for researchers in implementing differing models in the future. It holds value to the practitioners who may adopt more effective approaches in their organizations.

24.1.5 Contribution to the Field and Profession of Industrial Engineering

The industrial engineering profession and research field would benefit from this research, as it demonstrates better ways to economize on time, materials, money, energy, work hours, and other resources that may delay productivity. As a result, more goals can be met expediently and efficiently. Further, the findings of this study may help engineers learn how to categorize and conserve systems with the most up-to-date technologies that will enhance productivity across the board.

The easy-to-read language in this study benefits any reader seeking to learn about change management models, but also it benefits professionals seeking to improve their organization(s). The study not only shows unexplored avenues of change management research but also demonstrates how essential and effective change management is for any organization.

Finally, the paper is strategically organized to benefit any reader type. Section two highlights the high-level literature review of existing research on the subject. The third section explains the used research methodology. Section four identifies the findings alongside the study's analysis. Finally, the fifth section outlines implications regarding the findings, suggestions for future research, research limitations, and general conclusions.

24.2 Literature Review

24.2.1 Lewin's Change Management Model

The most influential change management model was Lewin's model [10]. Lewin proposed a planned and organizational three-stage change manage model that contained unfreeze, change, and refreeze [11]. This three-stage model was being proposed to explain and to guide how to initiate, manage, and stabilize the process of the organizational changes [10]. This change management model is also referred to as the force field change management model.

Lewin described the organization as a balance that is staying in a stable status, which is formed by reverse equal forces. He reckoned that many driving forces exist in the organization, including the pressure of the changes, the pressure of the competition, the transmission of the new technology, etc. [12]. Additionally, there are the resisting forces to balance these driving forces: solidified organizational conventions and customs, the agreement with the trade union, the organizational culture and conceptions, etc. Only a certain force is being rested by another force, and then the balanced status can be achieved within an organization [13]. Lewin believed that the motivation of driving the changes within the organization is relying on the interaction between the driving force and the resisting force [13]. These two types of forces will replace each other along with the change of the environment, and the organization has been seeking to balance the status between these two types of forces. Whenever the organization achieved a new balance, it had just experienced the fierce changes [14].

Lewin declared that the change process of any organization could be imagined as the transition from the current balanced status to the desired status or the new balanced status [14]. Therefore, he proposed the three-stage theory. The first, the unfreeze stage, is prepared for change, in which the change has already been understood as necessary. Moreover, the organization is prepared to move out of its comfort zone. In this stage, the basis of the force field analysis database is to weigh the driving and resisting forces [15]. The mission in the unfreezing stage is to figure out the resisting forces of the organizational changes, and the solutions to conquer the resisting forces must be adapted to further sketch the blueprint of the organizational changes. Therefore, the direction of the organizational changes can be ensured to complete the organizational change proposal. During the second change stage, Lewin reckoned that the change is a process rather than an event [16]. This process is called a transition, which refers to the internal movement, when people respond to the change. The mission in this stage is to operate the specific change movements, following the finished change proposal so that the organization can transit from the current model to the target model [17]. During this stage, the role model shall be established to guide the new working attitudes and working behaviors. The change is the process of comprehension, which is being completed by acquiring the new concept and information. Thus, the communication styles and the cooperation patterns shall be particularly emphasized. The third stage proposed by Lewin is the freeze stage [18]. After organizational changes, both individuals and the organization are more likely revert back to the previous status. If so, the manager of the change project should adopt the methods to ensure the consolidation and the strengthening of the new behavioral patterns. The necessary strengthening methods, such as regulations and policies, must be adopted in the freeze stage [19]. Consequently, the new working attitudes and working behaviors can be stabilized for the organization to achieve a new balance. Without this stage, the result of the change management might vanish, which will cast the contemporary influence on the organization and its members.

24.2.2 The Systematic Change Model(Kast)

The systematic change model is formed based on the General System Model that was being proposed by Bertalanffy [20]. The systematic change model aimed at applying the General System Model into the organizational change practices, which also worked out some useful theoretical frames. The major representatives of the systematic change model include Kast, Rosenzwig, etc. [21]. They added the organizational change analysis into the foundation of the open system model, which formed the systematic change model [22]. The so-called open system model mainly emphasizes that the organization is not only an artificial open system but is also an integration of all types of subsystems. This model contains three parts, which are the input, change elements, and the output [23]. The input refers to the vision, mission, strategic planning of the company, while the change elements are the organizational objective, human labor, social elements, organizational structure, organizational culture, etc. The output refers to the organizational integrated effectiveness [1, 24].

By this model, the representative Kast of the systematic theory proposed that there are six steps to implement the organizational change. (a) Inspecting the status. The project manager should make a thorough review and evaluation of the internal and external environment of the organization for changes to not be neglected. (b) Identifying the problems. The project manager should identify and analyze the problems that exist in the organization to ensure the need for the organizational changes. Moreover, the particular information about the changes can be provided to the related department of the organization. (c) Identify the gap. The project manager should explore the gap between the current and the desired status to analyze the problems. (d) Design the solutions. The project manager should propose and evaluate many solutions and alternatives, and the selection should be done after discussion and performance assessment. (e) Implement the changes. The project manager should implement the change proposal, which depends on the selected solution and plan. During the implementation of the change proposal, the side effects of the changes must be reduced and controlled to a great extent. (f) Give the feedbacks on the change management. The project must make the critical review of the new results of the output [25]. Through timely feedback, the consistency between the external environment status, as well as the internal environment status, can be inspected. When new problems are generated, these six steps can be recycled.

24.2.3 Levitt Change Model

The Levitt proposed the systematic model for change of the entire enterprise or other organizations. He believed that the content of the organizational change should include four aspects, which are the mission, human resources, technology, and the organizational structure [26]. The mission refers to the objectives and aims established by the organization. For the enterprise, the mission is to provide the products and services that are needed by the society [27]. Down to the internal enterprise, this mission is being distributed into the detailed working tasks in many aspects. The changes on the products and services, such as the adjustment of the product structure, the manufacturing of the new products, all belong to the important contents of organizational change [28]. Regarding the human resource, it refers to the status of the leaders and employees in the organization, in which the working attitude, working competence, working expectance, beliefs, and working styles are being evaluated [29, 30]. To organize the human resource structure is another essential content within organizational change. Technology refers to the technological instrument and the technical solutions for manufacturing products and maintaining operations [31]. The major contents concerning the technology within the organizational change refer to the improvement of the technology, the implementation of the new technology, the adoption of the new materials, etc. To the change management on the organization structure, the responsibility allocation, structure design, and coordination pattern are all being involved [32].

From the organizational change system model proposed by Levitt, it can be indicated that the dependence of the change management among these four aspects is relatively high. For example, when the company adjusts the product structure, it is also demanded that the manufacturing technology should also be improved. Moreover, the adjustment of the product structure requires that the human resources should improve their quality. Accordingly, adjustment of the organizational structure and labor-management are also required. The change management of these four aspects usually happens at the same time.

24.2.4 Kotter's Change Model

The organizational change model established by Kotter was being proposed by the summary of the enterprise's organizational change practices from the 1980s to the late 1990s [33]. In his writing, he stated that the failure of the organizational change was due to such mistakes made by the senior leaders. Firstly, the senior leader might fail to develop a sense of urgency on the demand for organizational change [34]. Secondly, the senior leaders might fail to find a powerful and effective leader's alliance to take charge of the change management. Thirdly, the senior leaders might fail to wipe out the obstacles in realizing the vision planning. Moreover, the senior leaders might lack effective communication about the vision planning [35]. Furthermore, the senior leaders might fail to make a systematic plan, so that the short-term economic interest can be acquired. The senior leader might announce the success too early, and the senior leaders might fail to consolidate the organizational change in the deep organizational culture [36].

Therefore, Kotter established an eight-stage process to guide the change management in the organization. He reckoned that the success rate for the organization change would be increasingly high if the organization strictly complies with the guidance of these eight stages. These eight stages include: (a) Establish the sense of urgency. The project manager should consider the confronted market and the competition of the organization. He also should identify and discuss the current crisis, the potential hazards, and the great opportunities, so that the sense of urgency can be established among the members of the organization. (b) Form the leader's alliance. The project manager should form a powerful change management leader's alliance to guide the change and to inspire the coordination among the organization members. (c) Develop the vision and strategy. The project manager should construct and organize the brand new strategic planning by effectively communicating the vision and strategy with the organization members. (d)Communicate the vision changes. The project manager should utilize all kinds of media approaches to operate the wide communication with the organization members about the new vision and strategy. In this stage, the leader's alliance should make good examples of advertising and implement the new organizational objective and behaviors [37]. (e) Authorize the members to strive for the future. The project manager should wipe out the obstacles in front of the organizational change. The system that is harmful to the vision should be cleaned out and the innovation in the organization should be inspired. (f) Make a systematic plan and achieve the short-term economic interest. The project manager should do the planning for the improvement of the actual performance. Also, the members who participated in the performance improvement and achieved the short-term economic benefits should be rewarded [38]. (g) Consolidate the organizational change. The project manager should utilize the growing reputation to continuously change the system that is not consistent with the vision planning. (h) Implement the new models deep into the organizational culture. The project manager should make clear the position of the change management in the organizational culture [39].

24.2.5 ADKAR Model

The ADKAR model was developed by Prosci in 1998, which focused on conditioning the organization for change. The ADKAR process characterizes the process of the individual change in five key stages (see Fig. 24.1) [40]. (a) Awareness. This investigates whether people are clear about the planned changes, the necessity, and the significance of the changes in the organization. (b) Desire. Investigates whether people are willing to accept the changes. (c) Knowledge. Investigates whether people master the necessary knowledge to operate the change management. (d) Ability. Investigates whether people are capable enough to lead and to implement the organizational change. (e) Reinforcement. Investigates whether people have the solutions to consolidate the new formation and results [41].

24.3 Methodology

The chosen methodology is crucial to guide the direction of the paper and collect appropriate data. With well-managed methodology, we can present an organized outline and use good data to reach the conclusions identified.

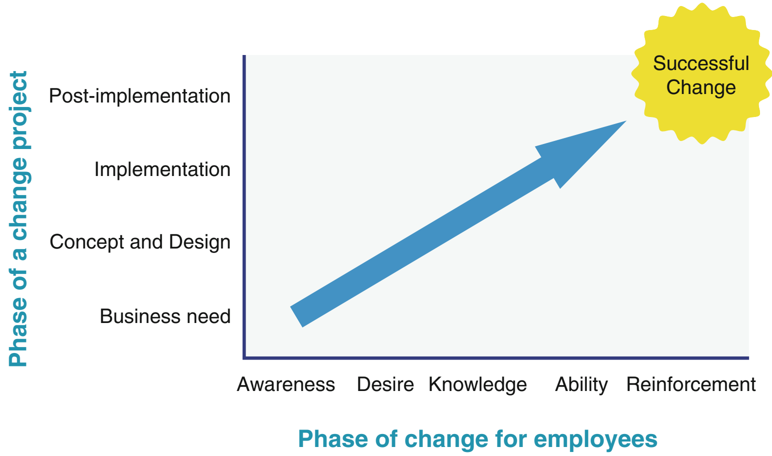

Fig. 24.1 The ADKAR model. Source: [40]

24.3.1 Data Collection

Good quality data translates to a good quality research paper. Two forms of data are collected for this sort of research. First, there is primary data, or first-hand data. It is often designed and made precisely according to specific research [42]. The consistency and the practicability of the primary data are extremely high compared to other data. Primary data can be collected two ways: through questionnaire and also through interviews [43]. Because both methods are more challenging, collecting primary data for daily research is also a challenge. Time, region, and sampling method, all may have negative impacts on data collection [44].

The second form of data, more often collected, is second-hand data, or documents released by authorities, organizations, and individuals. The data may be derived from annual reports, articles, and documents, and therefore may be more reliable. Second-hand data is most often collected for this type of research since it is more accessible. As a result, the cost of collecting this data is much lower. Unfortunately, there are also some disadvantages. For example, the data may not perfectly conform to the research topic as primary data would.

This study utilized second-hand data. Its foundation was in existing academic research regarding change management models. More specifically, journal articles were analyzed the most.

24.3.2 Data Analysis Method

Three types of research methods may be adopted, depending on the type of data that is collected. The first is quantitative analysis, used to understand the relationships and characteristics of numerical data. In other words, it focuses on the quantity of the data, wherein the objectivity of the fact is valued alongside the interrelations and cause-effect of the data [45].

Secondly, qualitative analysis helps to understand different types of data. This method investigates both internal and contradictory changes [46]. This emphasizes the quality of the data, such as historical fact and descriptions. Qualitative analysis is best used when the assembled data is purely textual.

The third is the most comprehensive data analysis method. It involves an integration of quantitative with qualitative analysis. This method was not employed in this study. Rather, this study used a qualitative analysis since the data collected excluded numerical data. Qualitative analysis helps compare the application of different change management models under different circumstances.

24.4 Findings of the Change Management Models

24.4.1 Comparison of the Five Leading Change Management Models

In the current literature field, there exist many theories about the change management model. Most of them share likenesses in some respects. In this paper, three leading change management models will be precisely investigated to explore the similarities and differences among these models. The first selected model is Kotter's eight steps for leading organizational change, while the second is the Lewin's change model, and the last one is the ADKAR model.

Kotter's eight steps for leading organizational change emphasized the leading change, rather than the management of the leading change. John Kotter was an expert on the leadership and the change management, which made a precise conclusion of the failure of the change management because of the eight mistakes made by the leaders. In other words, the leaders are being placed at the top position in implementing the change management. The model proposed by Kotter let the leaders bear the heavy responsibility to lead the organizational change. Calder [47] stated that leadership needed to be leading the change. In his opinion, the organizational change can be completed all over the organization, but the key participants or players of the organizational change shall be the leaders. Without the support from the leaders, the organizational change implementation in the company will become extremely difficult. Furthermore, there are many advantages and disadvantages of Kotter's change management model. As to the advantages of Kotter's change management model, it is relatively easy to follow the guidance of the change model of Kotter's. The Kotter's change management model clearly demonstrates the major contents and the core of each step. Moreover, the Kotter's change management model does not pay close attention to the change itself. Instead, it focuses on the preparation and the acceptance of the change, so it is helpful for participants to make the easy transition. This model also emphasizes the communication among all stages, which might be greatly useful for the traditional hierarchies. The disadvantages of the Kotter's change management model also cannot be ignored. Firstly, once the process of change management model begins, it is hard to convert the direction. During the implementation of the Kotter's change management model, if the individual needs are ignored, then this change activity will easily lead to employee frustration [48].

The Lewin's change model is a quite simple model that was invented by Kurt Lewin [47]. It assumes that change is planned, so no matter which type of change is being implemented, people are the foundation of the change. According to Calder, the model focuses on diminishing one's resistance to change. This is done by highlighting two types of forces in a business, which are driving forces and restraining forces. A person's reasoning and motivation to change is the driving force, while the restraining force is the reason why the person hesitates to change [47]. However, there exist many disadvantages that have been fully recognized by many researchers. For example, some researchers blamed that the change management model proposed by Lewin is too simplistic and mechanistic, especially when the implementation of the current organizational change is a continuous and complicated process. Moreover, Lewin's change management model is being regarded that it can be only integrated into progressive and isolated projects, which are not capable of integrating the radical change.

ADKAR is the abbreviation for the words awareness, desire, knowledge, ability, and reinforcement. Calder [47] demonstrated that the ADKAR model was invented to integrate change into government, business, and the society. In this change management model, the individual level is in focus. The principles stated in the ADKAR model can be applied to plenty of people, as the core of the ADKAR model is people. Therefore, this model seems quite difficult to implement into the project, since there is not a list of steps to guide the implementation of the change management in the project.

In the changing period, there are actually many elements being involved. This is the reason for the frequent failure of the implementation of the change plans; too many people regard the change as an isolated activity, thus neglecting the involvement of other elements. The advantage of the Levitt change model is that an integrated change strategy is being proposed in this change model. However, this might be only suitable with the large scale of change project, and implementing this model seems to be redundant when changing only a small part.

Regarding the Kast Systematic model, the focus of this theory is again the people. To be precise, people are being over-concentrated during the whole changing period. More specifically, that people making the investigation on the business operate the first step. The following emphases are on the people themselves, rather than on the change implementation.

24.4.2 *Similarities and Differences Among Five Leading Change Management Models*

In this part, each step or component of the three leading change management models will be compared in detail. Furthermore, the comparison made on these change management models will be applied to the evaluation of the effectiveness of the organization change. By comparing each step in the ADKAR model with the stages in the Lewin's change management model, each step in the former model can be applied into the stages of the latter model. To be precise, the unfreezing stage of the Lewin's change model is parallel to the stages of awareness, desire, and the knowledge in the ADKAR model. Moreover, the changing stage in the Lewin's model is parallel to the stage of the ability in the ADKAR model. Also, the stage of refreezing in the Lewin's change management model is parallel to the reinforcement stage in the ADKAR model. Awareness in the ADKAR model is contained in the communication, which is one of the typical resistance-reduction strategies in the Lewin's model. While the knowledge in the ADKAR model is contained in training, it is another resistance-reduction strategy in the Lewin's model.

Concerning the similarities between the Lewin's change management model and the Kotter's Eight Steps for Leading Organizational Change, there are also likenesses about their specific stages. To be precise, the unfreezing stage in the Lewin's change management model is parallel to the first four phrases in the Kotter's Eight Steps. The changing stage of the Lewin's change management model is also parallel to the fifth to the seventh step in the Kotter's Eight Steps. Finally, the refreezing stage of the Lewin's change management model is parallel to the eighth step of the Kotter's Eight Steps. More specifically, the similarity between the Lewin's change management model and the Kotter's Eight Steps for Leading Organizational Change is that both Lewin and Kotter find that the full preparation must be done before the real start of the organizational change. Both have a clear comprehension of the importance of the resistance-reduction strategy. Also, all of the three-change management models prescribe the stages through which the change happens in the organization. These three change management models all concentrate on the integration of the knowledge about the behavior management, which also engages the organizational members in the process of the change.

Regarding the differences among these three leading change management models, there are several points that need to be clarified. The Lewin's change management model is different from the other two models, which can be indicated by its overall process of the planned change. To be precise, Lewin's change management model completely ignored the organizational change activities, so it is hard to follow just like mentioned before. The Kotter's model is much more specific than the Lewin's change management model.

Based on the detailed comparison of the three change management models, it is evident that each model does not contain certain components. To be precise, in the Lewin's model, the needed knowledge is being emphasized for leading the involved employees to initiate the change. However, the ADKAR model gives priority to desire in inspiring organizational members to start the change. Lewin only concentrated on overcoming resistance, which did not expand his concentration on other perspectives of the organizational change. For the Kotter's model, the leaders are being assigned too heavy of responsibilities to operate the organizational change. To be precise, the senior management is being given more concentration, rather than the employees and the individuals to initiate the organizational change. This point is different from the Lewin's change management model and the ADKAR model. Also, the explanation on the implementation of the specific change in each step is precisely provided in the Kotter's model. To make a comparison, the explanations provided in the Lewin's change management model and the ADKAR model are too simple. The explanation about each step in the Kotter's model contains more in-depth analysis than any of the other two models. Among these three change management models, all these models demonstrated that the barriers or resistance must be removed. Only the Kotter's model stated that risk-taking and innovative solutions could be adopted in doing such things.

Compared with Lewin's change management model, Levitt's change model specified particular variables within organizations, rather than the driving forces. These variables include the structure variables, the technological variables, the task variables, as well as the human variables. More specially, the structure variables include the authority system's communication systems and work flow. The technological variables include the equipment and machinery required for the task variable, as the task variables contain all the tasks and subtasks involved in providing products and services. People who complete tasks that are aligned with organizational goals (products and services) are human variables. Additionally, the Levitt's change model and Lewin's change management model differ because Levitt excludes how the external environment changes the variables.

Concerning the change model proposed by Kast, there are many similarities between the Kast change model and Lewin's force field change management model. Although Kast divided the thorough changing procedure into six major steps, they still share the great similarities. To be precise, the unfreezing period is equal to the first three steps being proposed by Lewin, and the second change phase is like the following two steps. However, there is one difference between these two theories, which is the final step of the change models. Lewin attempted to consolidate the changing achievement, while Kast tried to make further improvements on the change model.

24.4.3 Which Change Management Model Is the Most Effective?

Regarding the interviewing result made by Calder [47], the answers to this question varied from each other. From the comparison made among these three leading change management models, all of them share the overlaps in many aspects.

Furthermore, all of these three change management models contain the need for the consolidation of the organizational change, but they differ from each other in many aspects. For example, these three change management models focus on different audiences. Kotter's model pays more attention to the senior management, while the ADKAR model and the Lewin's model focus on the employees and individuals, respectively. Moreover, these three change management models focus on different group size. The ADKAR model can be applied to a large organization, but the Kotter's model cannot be engaged in a large organization.

After understanding this, the change management model might be selected differently, depending on the occasion. These three change management models might be the most effective models in different situations. Beginners are more likely to select the ADKAR change management model because it is easy to follow the guidance listed by this model because of the clearly defined steps. However, the Lewin's change management model seems to be too simple for the beginners. Furthermore, when the senior management is being involved in organizational change, the project manager is more likely to select the Kotter's change management model because this model is designed from the perspective of senior leaders. Under this kind of circumstance, the Kotter's change management model is more effective than any other models, so it is quite hard to answer this question. In general, the answers to this question vary to a great extent based on different circumstances.

24.5 Discussion

24.5.1 Implications for the Field of IE

For the project manager in the field of IE, he needs to know the vision of his organization. After comprehending the vision, the gap between the current status and the vision can be realized. According to the demonstration made by Lewin in his change management model, the resisting force must be reduced to provoke the change in the organization. Therefore, the resisting force in the IE field must be precisely figured out by the project manager. Moreover, the project manager needs to eliminate the barrier on the path to implementation of the organizational change.

The project manager needs to focus on two different perspectives in the organization of the IE field. After determining the expected achievement of the organizational change, the major activities shall be primarily separated into two lines, including the implementation of senior management and ordinary employees. Regarding the senior management, the project in the IE field should adopt the Kotter's change management model because the responsibilities of the senior leaders are precisely prescribed in this model. As to the individual and employees, the project manager in the IE model can adopt the ADKAR model to implement the organizational change. Since the ADKAR model can be applied to the large organization, the project manager should be extremely cautious at every step.

24.5.2 Application in the Field of IE

The engineering industry refers to the subject that improves the integrated system, which is formed by the people, materials, equipment, resources, as well as the information. This subject comprehensively applies to the knowledge of mathematics, physics, and social science. Moreover, the rationale and solutions for the engineering analysis and design are involved. The IE is a methodological science to eliminate waste, increase productivity, and decrease cost. The application of the change management model shall be the implementation of lean production. The objective of implementing the lean production is the perfect application of the change management model, which is about to transit from the current stable status to the ideal status. Implementing the lean production shall be the ideal status for the organizational change in the IE field, since the awareness of the IE field is the concept of cost and effectiveness. The IE field constantly seeks for the best-integrated benefit, and the increase of productivity shall be the major objective in the IE field. Therefore, the establishment of the sense of cost and effectiveness must be complemented in the IE field. Once the best-integrated benefit cannot be achieved, the need for the change management can be highly realized. Consequently, this is consistent with the first stage of the ADKAR change model.

24.5.3 Organizational Implications

Research on different change management models demonstrates their usefulness for adoption in business projects and project management. Adopting the right change management model can help a team develop the right skills to reach company and project goals. As a result, this research emphasizes the importance of top-down and bottom-up approach to leadership regarding project, operations, and process management. Such models also impact many elements of an organization. Both leadership and management ought to have the appropriate training and skills to utilize change management models for the organization's success. This study demonstrates that adopting the right change management model is often overlooked. Instead, leadership focuses on the financial elements of a business, which is detrimental in the long-run. A good long-term strategy incorporates a good understanding and adoption of the right change management model. Doing so would help the organization in the long run to reach ultimate success.

24.5.4 Managerial and Team Implications

This research provides opportunities to plan for projects and overall performance of an organization more effectively. More effective management may result as leaders become more educated on the different change management models and their use in differing environments. As a result, teams and the entire organization may also learn how to accordingly improve organizational performance and effectiveness. Recognizing gaps in performance helps teams and leadership to improve to thus benefit the project and achieve ultimate goals. This study also demonstrates the benefits of a more comprehensive training program for project and organizational performance and effectiveness. Team and organizational performance can be drastically improved, as well as proper leadership and management.

24.5.5 Implications and Applications to Fields of Project Management and Engineering Management

Engineers are also impacted by the findings of this research study. Today's engineers must be able to provide economically viable solutions to problems by using their knowledge in technology and mathematical tools. Understanding the business management side of a project may help engineers do their jobs and provide the best solutions.

Management and engineering concepts are scientific, which makes them overlap and interrelate. Engineering has actually improved many projects though better management. Thus, this study explained which change management models can be used to benefit engineers, as well as project managers. Project management and operational performance is fundamental to the IE/EM profession, as well as the research field. Today, every field of business requires some form of project management to be successful. Thus, the relationship between engineers and change management models cannot be overlooked. System engineers, project managers, and other experts in IE/EM may benefit from this study and improve their performance to achieve project and organizational goals.

24.6 Conclusion

24.6.1 Limitations

The major limitation was the limited sample size, which created potential bias in the findings. The key factors studied only related to the small sample size, in terms of project environments, and therefore may not necessarily also be applied to other areas such as supply chain management, operations, and strategic management. Exclusive conclusions make for another limitation.

Additionally, this research only collected secondary data because of time and region limits. Collecting primary data may have been more beneficial for this study. Similarities and differences between the leading change management models were discussed, which excluded other methods that may also be beneficial to varying organizations. Finally, the study only focuses on theoretical analysis of the leading change management models and therefore does not apply to real-world cases. This confines the research findings and makes it hard to extrapolate and apply to different areas.

24.6.2 Future Research

Additional research can be conducted to explore the relationship of change management models in other industries and managerial settings. How the models are impacted by such settings may also be an interesting avenue of research. Viewing change management models from different perspectives, such as cultural, organizational, and strategic viewpoints may also shed light on the best change management models for differing settings and organizations. Such analysis would shed light on how the models are affected by culture, strategy, human resources, and operations.

24.6.3 General Conclusions

Along with the process of the globalization since the 1980s, most of the industries and companies are confronting the increasingly threatening crisis from the external environment. Therefore, most of the organizations are willing to change, which makes scientific change management extremely important in current society. The key for the organization in direct competition is also relying on organizational change. Well-managed change will lead the organization on the step to sustainable development, which is also the formation of the core competitiveness advantage for an organization. However, current research on change management model is concentrating all on theoretical analysis, rather than research on practical application in daily life. Recommendations on future research shall be the practical application of theories in real cases in daily life.

In this research paper, a precise investigation of the leading change management model is being made. After making a precise comparison, there exist many change management models, such as Lewin's change management model, Kotter's theory, ADKAR, etc. Among these change management models, there are five that are being analyzed in the literature field, including the Lewin's change management model, the Kotter's change model, the ADKAR model, the Systematic model, and Levitt's model. These five change management models share overlaps in many aspects, such as the major contents in the major stages being listed in each model. At the same time, they differ from each other to a great extent, so they could be effective under different circumstances. Moreover, the comparison of the leading change management models provides great indications for the project manager in the IE field, as well as for the entire IE field.

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