Industrial research and development capacity building

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Abstract

Thailand faces significant challenges in aligning academic research with industrial needs and fostering robust R&D capabilities within businesses. The Industrial Research and Development Capacity Building (IRDCap) initiative was implemented to address these issues and enhance Thailand's innovation ecosystem. The program employs a dual approach: Train-the-Trainer (TTT) to develop academic expertise, and IRDCap Consulting to provide tailored support to businesses. It utilizes a comprehensive framework for developing R&D blueprints and roadmaps, supported by a central digital platform for monitoring and communication. Over five years, IRDCap trained 489 trainers and engaged 201 companies across various sectors, predominantly in agriculture and food. The program generated a valuation of 241.2 million US dollars, stimulated 28.1 million US dollars in investment, and created over 750 high-value jobs. Case studies demonstrate successful implementation of R&D roadmaps leading to product innovations and market expansion. IRDCap effectively bridges the gap between academic knowledge and industrial application, contributing significantly to Thailand's R&D capacity. The program's success highlights the importance of structured, collaborative approaches in fostering innovation, the effectiveness of the Triple-Helix model in driving economic development, and the need for continued adaptation to dynamic business environments.

Keywords: Research and development (R&D), Triple-Helix model, R&D roadmap, R&D blueprint, Thailand.

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10

เชิงนามธรรม

ประเทศไทยกำลังเผชิญกับความท้าทายสำคัญในการปรับทิศทางการวิจัยทางวิชาการให้สอดคล้องกับความต้องการของภาคอุตสาหกรรม และการส่งเสริมขีดความสามารถด้านการวิจัยและพัฒนาที่แข็งแกร่งภายในธุรกิจ โครงการเสริมสร้างขีดความสามารถด้านการวิจัยและพัฒนาในอุตสาหกรรม (IRDCap) ถูกนำมาใช้เป็นเครื่องมือในการแก้ไขปัญหาดังกล่าว และเสริมสร้างระบบนิเวศนวัตกรรมของประเทศไทย โดยโครงการนี้ใช้แนวทางแบบคู่ขนาน ได้แก่ การฝึกอบรมผู้ฝึกสอน (Train-the-Trainer หรือ TTT) เพื่อพัฒนาความเชี่ยวชาญทางวิชาการ และการให้คำปรึกษา IRDCap เพื่อให้การสนับสนุนที่เหมาะสมกับธุรกิจ ซึ่งโครงการนี้ใช้กรอบการทำงานที่ครอบคลุมสำหรับการพัฒนาพิมพ์เขียวและแผนที่นำทางการวิจัยและพัฒนา โดยมีแพลตฟอร์มดิจิทัลกลางสนับสนุนการติดตามและการสื่อสาร โดยในช่วงเวลา 5 ปี IRDCap ได้ฝึกอบรมผู้เชี่ยวชาญไปทั้งสิ้น 489 คน และมีส่วนร่วมกับบริษัท 201 แห่งในหลากหลายภาคส่วน โดยเฉพาะอย่างยิ่งในภาคการเกษตรและอาหาร โครงการนี้สร้างมูลค่าประเมิน 241.2 ล้านดอลลาร์สหรัฐ กระตุ้นการลงทุน 28.1 ล้านดอลลาร์สหรัฐ และสร้างงานมูลค่าสูงกว่า 750 ตำแหน่ง โดยกรณีศึกษาแสดงให้เห็นถึงความสำเร็จในการนำแผนที่นำทางการวิจัยและพัฒนาไปใช้ ซึ่งนำไปสู่นวัตกรรมผลิตภัณฑ์และการขยายตลาด ซึ่ง IRDCap สามารถปิดช่องว่างระหว่างความรู้ทางวิชาการและการประยุกต์ใช้ในอุตสาหกรรมได้อย่างมีประสิทธิภาพ ส่งผลอย่างมีนัยสำคัญต่อขีดความสามารถด้านการวิจัยและพัฒนาของประเทศไทย ความสำเร็จของโครงการนี้ชี้ให้เห็นถึงความสำคัญของแนวทางที่มีโครงสร้างและความร่วมมือในการส่งเสริมนวัตกรรม ประสิทธิผลของโมเดลไตรภาคี (Triple-Helix) ในการขับเคลื่อนการพัฒนาเศรษฐกิจ และความจำเป็นในการปรับตัวอย่างต่อเนื่องเพื่อรับมือกับสภาพแวดล้อมทางธุรกิจที่เปลี่ยนแปลงตลอดเวลา.

คำสำคัญ: วิจัยและพัฒนา, โมเดลไตรภาคี, แผนที่นำทางการวิจัยและพัฒนา, พิมพ์เขียวการวิจัยและพัฒนา, ประเทศไทย.

Introduction

Research and Development (R&D) plays a crucial role in driving innovation and enhancing productivity across various sectors of the economy. Studies have consistently demonstrated that the social rate of return on R&D investments is substantial, under-scoring the significant positive externalities generated by these activities (Evenson et al., 1979; Alston, 2010). Similarly, research has shown that creative human capital plays an increasingly vital role in economic development as industrial economies transition to knowledge-based creative economies (Kuznetsova et al., 2022). This high social return justifies continued emphasis on R&D as a key driver of economic growth and technological advancement.

Global trends indicate a projected increase in R&D investments, with Asian countries expected to experience particularly robust growth in both economic output and R&D expenditure. This growth trajectory in Asia is anticipated to outpace that of other regions worldwide. Within this global landscape, the United States and China are poised to maintain their positions as leaders in economic growth and R&D investment increases (Mehlman, 2024).

In the United States, R&D investment has reached substantial levels, with annual expenditures approximating 495 billion US dollars. The private sector plays a dominant role in this investment, contributing about 67% of the total R&D spending. Complementing this private investment, the Federal government allocates approximately 150 billion US dollars annually to R&D activities. These funds are distributed across Federal laboratories, universities, and other research organizations (Armstrong et al., 2019). This public-private partnership in R&D funding exemplifies a balanced approach to fostering innovation, combining market-driven research with government-supported scientific inquiry.

The synergistic relationship between industry and academia has been widely recognized as a pivotal factor in enhancing research and development (R&D) outcomes. Recent research has highlighted how national culture significantly influences digital transformation success through its effects on digital competencies and information system management practices (Alshammari & Alshammari, 2023). University-industry linkages facilitate multifaceted benefits, including knowledge transfer, talent acquisition, and resource sharing, which collectively contribute to accelerated innovation and improved problem-solving capabilities (Phongthiya et al., 2022; Murga Pinillos, 2024). These collaborations enable firms to access cutting-edge research and specialized expertise, while simultaneously providing universities with practical insights and funding opportunities.

The symbiosis often results in expedited commercialization of research findings and a more robust innovation ecosystem. Moreover, such partnerships can mitigate R&D risks and costs for both parties, making ambitious projects more feasible and potentially leading to breakthrough technologies. The long-term research focus of universities complements the more immediate, application-oriented approach of industry, creating a balanced R&D portfolio that addresses both fundamental questions and market needs. Consequently, industries with strong university linkages tend to exhibit enhanced R&D success, manifesting in increased patent applications, product innovations, and overall competitive advantage in their respective markets (Opassuwan & Wannamakok, 2024).

Methodology

This research employs a mixed-methods approach combining quantitative program evaluation with qualitative case study analysis to assess the implementation and impact of the Industrial Research and Development Capacity Building (IRDCap) initiative in Thailand. The study spans a five-year period (2019-2024), utilizing both primary and secondary data sources to provide a comprehensive understanding of the program's effectiveness in enhancing R&D capabilities within Thai industries.

The quantitative component involves systematic collection and analysis of program performance metrics, including: number of trained consultants, participating companies, established R&D units, economic value generation, investment stimulation, and job creation. Data collection was facilitated through the IRDCap Central Platform, which served as a centralized repository for all program-related information and metrics. The platform's structured data collection protocols ensured consistency and reliability in performance measurement across different regions and industry sectors. This was supplemented by regular progress reports, financial documentation, and participant surveys that provided quantitative insights into program outcomes.

The qualitative dimension employs multiple case study methodology, analyzing specific instances of program implementation across various industry sectors. Primary data was gathered through semi-structured interviews with key stakeholders, including program managers, trainers, and participating company representatives. Documentation review included analysis of R&D blueprints, implementation reports, and feedback from knowledge exchange sessions. The research framework was guided by the Triple-Helix model of innovation, examining the interactions between government initiatives, academic institutions, and industry partners. This methodological triangulation, combining multiple data sources and analytical approaches, enhances the validity and reliability of the findings while providing rich contextual understanding of the program's impact on Thailand's R&D landscape.

Research and Development (R&D) Capacity Building in Thailand

Research and development (R&D) capacity building in Thai industry is a focal point of study, given its critical role in driving innovation and economic growth. An examination of Thailand's R&D expenditure reveals a modest investment of 13.4 billion US dollars, which accounts for only 1.1% of the country's GDP. This level of investment positions Thailand at the 36th rank globally in terms of R&D spending (Dutta et al., 2022). Such figures underscore the need for increased investment in R&D to enhance Thailand's competitiveness in the global innovation landscape.

In the Global Innovation Index 2022, published by the World Intellectual Property Organization (WIPO), Thailand ranks 43rd overall, indicating a moderate performance in innovation on the global stage (Dutta et al., 2022). This ranking suggests that while Thailand has made progress in fostering innovation, there is still considerable room for improvement to join the ranks of leading innovative nations. A closer examination of specific indicators reveals both strengths and areas for development in Thailand's R&D landscape. Business expenditure on R&D stands at 0.8% of GDP, placing Thailand at the 30th position world-wide. This relatively higher ranking in business R&D suggests a growing recognition among Thai companies of the importance of innovation in maintaining competitiveness. However, the percentage of knowledge-intensive employment in Thailand is only 15.1%, resulting in a lower global ranking of 90th. This disparity highlights a potential mismatch between R&D investments and the creation of high-skilled jobs in knowledge-intensive sectors.

Research and development (R&D) in Thailand faces significant challenges in aligning academic research with industrial needs. Most Thai R&D institutes primarily focus on basic research, resulting in a disconnect

between developed technology and industrial demand (Karaveg et al., 2014). This misalignment has prompted the government to take proactive measures to bridge the gap between academia and industry. In response, several projects have been initiated to support industrial R&D, with the dual objectives of enhancing the country's research activities and fostering stronger university-industry linkages (Siripitakchai & Miyazaki, 2015; Wannakul et al., 2019).

The Thai government plays a pivotal role in nurturing R&D, particularly among small and medium-sized enterprises (SMEs). Through a comprehensive evaluation process that considers factors such as entrepreneur capabilities, researcher expertise, and project details, the government selects and supports industrial R&D projects for SMEs (Karaveg et al., 2014). This targeted approach aims to stimulate innovation and technological advancement within the SME sector, which forms a crucial component of Thailand's economy.

Despite these efforts, researchers and developers in Thailand face several key challenges. A notable concern is the negative relationship between R&D intensity and firm performance in Thai SMEs (Suttipun & Insee, 2024). This inverse correlation suggests that SMEs struggle to translate their R&D investments into tangible improvements in business performance, highlighting the need for more effective R&D strategies and support mechanisms. Thailand's economic development has been hampered by what is commonly referred to as the middle-income trap. This stagnation is largely attributed to the relatively low technological learning capacity of firms, a situation exacerbated by decades of ineffective science, technology, and innovation policies (Intarakumnerd, 2019).

Innovation-driven enterprises (IDEs) in Thailand encounter specific impediments that hinder their growth and effectiveness. These challenges encompass the quality of entrepreneurs, product-market fit issues, and inadequate support systems (Thawesaengskulthai et al., 2024). These factors collectively impact the depth of knowledge within IDEs, the efficacy of business incubation programs, and the overall effectiveness of laws, measures, and policies designed to support innovation capability development. Addressing these impediments is crucial for fostering a more robust and dynamic R&D ecosystem in Thailand.

Industrial Research and Development Capacity Building (IRDCap) Initiative

The Ministry of Higher Education, Science, Research and Innovation (MHESI) in Thailand serves as the primary government agency responsible for overseeing higher education and fostering the research and development ecosystem. This ministry plays a crucial role in shaping the country's innovation landscape and aligning educational institutions with national development goals. MHESI has established a comprehensive strategic framework to guide its activities and initiatives. The key strategic objectives of the ministry include: (1) enhancing economic competitiveness and sustainable self-reliance through higher education, science, research, and innovation; (2) elevating social and environmental standards through the application of higher education, science, research, and innovation; (3) advancing cutting-edge science, technology, research, and innovation; and (4) developing human capital within higher education institutions and research organizations. These strategic pillars demonstrate a holistic approach to leveraging education and innovation for national development.

One of the notable initiatives launched by MHESI is the Industrial Research and Development Capacity Building (IRDCap) initiative. This program aims to strengthen the research and development capabilities of businesses in Thailand. The specific objectives of IRDCap include enabling businesses to develop comprehensive R&D blueprints, cultivating expertise in innovation and technology management within companies, and facilitating the establishment of dedicated R&D units within business entities. A distinguishing feature of this initiative is its adoption of the Triple-Helix model, which promotes collaboration between government, private sector, and educational institutions. This collaborative approach is designed to create synergies and enhance the overall effectiveness of R&D efforts in the country.

The IRDCap represents a significant initiative in Thailand's national innovation ecosystem, implemented through a decentralized network of Regional Science Parks (RSPs) (Poonjan et al., 2022; Wongwanich, 2022; Pairsuwan, 2023). This structure ensures comprehensive geographical coverage across the country, with four key RSPs strategically positioned: RSP North, RSP North-East 1, RSP North-East 2, and RSP South. The utilization of RSPs as the primary operational units for IRDCap leverages their established infrastructure and regional expertise, facilitating more effective engagement with local industries and academic institutions (Cooke et al., 1997; Asheim & Isaksen, 2002).

The decentralized approach of IRDCap through RSPs aligns with contemporary theories of regional innovation systems, which emphasize the importance of localized knowledge networks and context-specific innovation strategies (Tödtling & Trippl, 2021). By operating through regionally embedded institutions, IRDCap can more effectively tailor its interventions to the specific needs, challenges, and opportunities of different geographical areas within Thailand. This structure also facilitates the diffusion of innovation practices and knowledge across regions, potentially leading to more balanced economic development throughout the country (Lundvall & Borrás, 1997).

Furthermore, the involvement of RSPs in IRDCap exemplifies a Triple-Helix model of innovation, where government initiatives (represented by the national IRDCap program) intersect with academic institutions (embodied in the RSPs' university affiliations) and industry (the target beneficiaries of the program) (Etzkowitz & Leydesdorff, 2000). This tripartite collaboration is crucial for fostering an environment conducive to sustained innovation and technological advancement, particularly in emerging economies striving to enhance their global competitiveness through research and development capabilities (Intarakumnerd et al., 2002).

The success and sustainability of IRDCap projects are further bolstered by the RSPs' cumulative experience in managing complex, multi-stakeholder initiatives. Their proficiency in navigating the intricate dynamics between academic research, industrial application, and policy implementation positions the RSPs as ideal facilitators for the program (Perkmann et al., 2013). This expertise is particularly valuable in addressing the oft-cited challenges of bridging the gap between academic research and industrial application, a critical factor in the success of innovation-driven economic development strategies (Bruneel et al., 2010; Bozeman et al., 2013).

The IRDCap program represents a comprehensive approach to fostering innovation and enhancing R&D capabilities within Thailand's industrial sector. This initiative is structured around two interconnected yet distinct projects: Train the Trainer (TTT) and IRDCap Consulting, as illustrated in Figure 1. This dual-project framework is designed to create a sustainable R&D ecosystem by effectively bridging the gap between academic expertise and practical business applications.
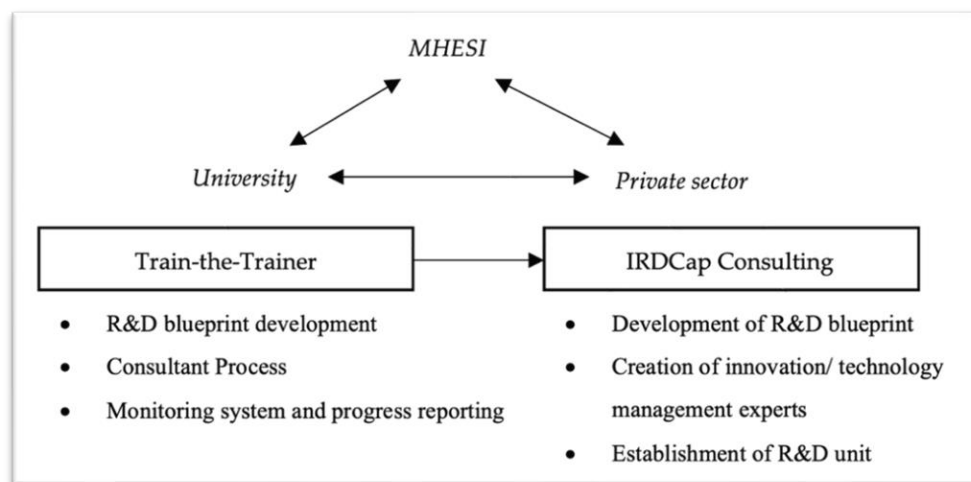
Figure 1. Conceptual Framework of IRDCap – a Triple-Helix approach.

At the core of this framework is MHESI, which serves as the central coordinating body. MHESI facilitates bidirectional relationships with both universities and the private sector, ensuring alignment between national innovation policies and the practical needs of industry. This tripartite interaction exemplifies the Triple-Helix model of innovation, where government, academia, and industry collaborate to drive economic and social development.

The TTT component focuses on developing a cadre of skilled consultants from academic institutions. This project encompasses three critical elements: R&D blueprint development, consultant process training, and the implementation of monitoring systems for progress reporting. By equipping academic professionals with these skills, the program aims to create a sustainable source of expertise that can be continually tapped to support industrial R&D efforts.

Complementing the TTT project, IRDCap Consulting represents the practical application of the developed expertise within the private sector. This component involves the development of tailored R&D blueprints for participating companies, the creation of innovation and technology management experts within these organizations, and the establishment of dedicated R&D units. This hands-on approach ensures that the knowledge and skills developed through the TTT project are effectively transferred and implemented within industrial settings.

Train-the-Trainer (TTT)

The Train-the-Trainer (TTT) project, a key component of the IRDCap initiative, focuses on building capacity for university academia to serve as trainers in developing research and development (R&D) capabilities within companies. TTT equips trainers with essential innovation and R&D management tools through an intensive 15-hour training program that emphasizes both hard and soft skills development.

The development of the course content follows a rigorous and comprehensive approach, integrating multiple sources of input and expertise. This includes stakeholder suggestions, extensive literature review, and expert knowledge. The program is structured into three primary modules covering hard skills, complemented by special lectures and integrated soft skills training.

The analysis module, allocated 4 hours, covers business trend analysis, business foresight, and gap analysis. It provides trainers with tools to assess current market conditions and future trends, such as SWOT, TOWS matrix, Business Model Canvas, Five Forces Model, and PESTEL (Martinez-Contreras et al., 2022; Pasaribu et al., 2023; Rizki & Wijaya, 2024). This module aims to develop understanding of the interplay between science, technology, and innovation while emphasizing the importance of key performance indicators (KPIs) in strategic planning.

The development plan module, also 4 hours, focuses on industrial research, technology blueprint development (Carvalho et al., 2013; Rennings et al., 2003), and capacity development. It addresses the identification and resolution of technology and innovation gaps within organizations, the development of technology blueprints and roadmaps, and the emphasis on sustainable capacity building.

The implement strategies module, another 4 hours, addresses strategies development and implementation. It ensures trainers can guide companies in executing their R&D plans effectively, focusing on translating plans into actionable strategies, developing R&D roadmaps and blueprints tailored to specific organizational needs, and considering relevant technologies and associated costs.

Complementing these core modules, the program includes 3 hours of special lectures on pertinent topics. These include overcoming challenges through open innovation (Elmquist et al., 2009), fostering innovative thinking in science and technology, and gaining insights into the future of industry from experts.

Soft skills are integrated throughout the program, particularly during workshop sessions. These sessions simulate real consulting scenarios, allowing trainers to practice and refine their communication, problem-solving, and advisory skills in the context of IRDCap consultations.

The structure of the TTT program can be summarized in Table 1.

Table 1.
Train-the-Trainer (TTT) program.

Module	Hrs.	Key Objective	Content Area	Workshop Activities
Analysis	4	Understand business trends, foresight, and gap analysis	Business trend analysis, foresight techniques, KPI setting	Conduct business trend analysis, environmental scanning
Development Plan	4	Address technology gaps, develop blueprints	Industrial research, technology blueprint development	Identify technology trends and gaps
Implement Strategies	4	Translate plans into actionable strategies	Strategies development and implementation	Develop R&D roadmap and plan
Special Lectures	3	Gain insights on innovation and industry future	Open innovation, innovation thinking in science and technology	

This comprehensive structure ensures that trainers are equipped with a holistic skillset to effectively support companies in developing their R&D capabilities, aligning with the broader objectives of the IRDCap initiative.

IRDCap Consulting

The IRDCap Consulting program represents a structured approach to enhancing research and development (R&D) capabilities within Thai businesses. The program begins with a rigorous selection process, wherein companies submit applications for participation. This selection phase employs multiple criteria, including organizational readiness, company size, and comprehension of the program's objectives. This multi-faceted evaluation ensures that participating companies are well-positioned to benefit from the program and contribute to its overall success.

Upon successful selection, companies are strategically paired with consultants drawn from a database of TTT graduates. This matching process is predicated on an initial assessment of compatibility between the company's specific needs and the consultant's areas of expertise. Such a tailored approach aims to establish a strong foundation for productive collaboration within the IRDCap framework, potentially enhancing the effectiveness of the consulting process.

The core of the IRDCap Consulting program is a comprehensive 20-man-day consultative process. The primary objective of this process is the development of detailed R&D blueprints for participating businesses. These blueprints are not generic templates but are instead tailored to address specific gaps in each company's R&D capabilities. Crucially, the development process ensures alignment between these R&D plans and the broader vision and strategic targets of the participating companies.

This hands-on, customized approach facilitates the practical application of R&D concepts and methodologies in real business contexts. By grounding theoretical knowledge in the specific challenges and opportunities faced by each company, the IRDCap Consulting program aims to produce more effective and relevant R&D outcomes. This methodology aligns with best practices in management consulting and organizational development, which emphasize the importance of context-specific interventions for maximum impact.

The consulting process follows a structured "expert journey," as illustrated in Figure 2. This journey serves as a consultation guideline, providing a standardized yet flexible framework for consultants to follow. While the specific details of this journey are not elaborated in the given text, the use of such a structured approach suggests a systematic method for guiding companies through the R&D blueprint development process.

By combining careful company selection, strategic consultant matching, and a structured yet tailored consulting process, the IRDCap Consulting program represents a comprehensive approach to building R&D capacity in Thai businesses. This methodology has the potential to contribute significantly to the broader goals of enhancing innovation and competitiveness in the Thai industrial sector.
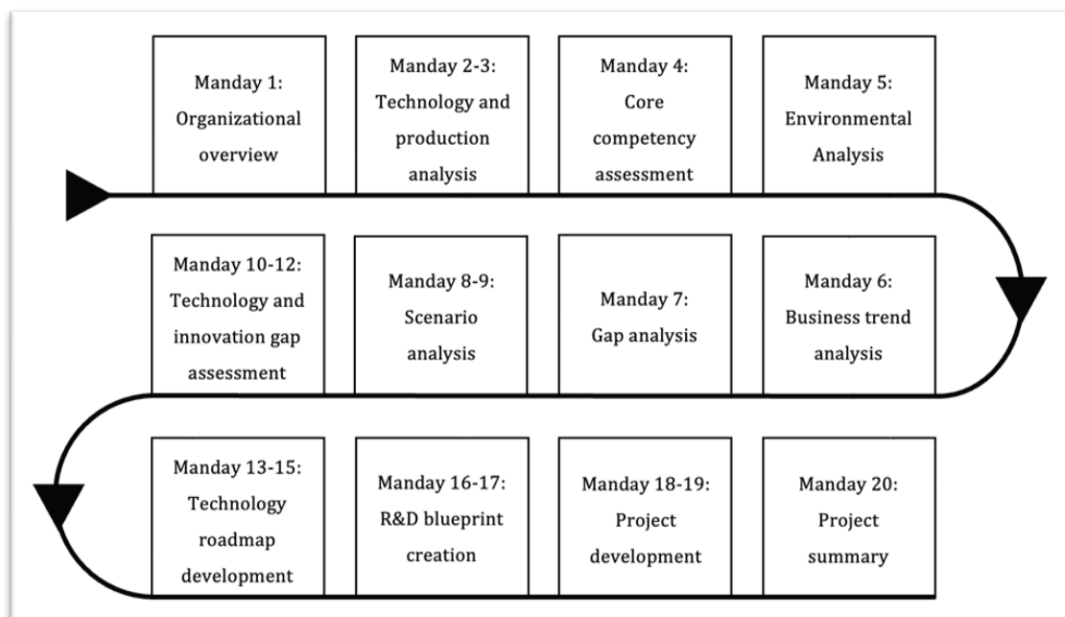
Figure 2. IRDCap Consulting - Expert Journey.

R&D Roadmap and Blueprint Development

The IRDCap program employs a comprehensive framework that delineates a strategic approach to transforming organizations into Research, Development & Innovation-Driven Enterprises (RDIDE) (Siripitakchai & Miyazaki, 2015; Dolińska, 2022). This framework, illustrated in Figure 3, outlines a systematic process of business analysis and planning aimed at enhancing innovation capabilities and competitiveness.

The model begins with a multifaceted business analysis that incorporates three key elements: business/market trends, technology trends, and foresight and scenario planning. These analyses serve as the foundation for developing or refining the organization's business model, which acts as the strategic core of the enterprise. This business model, in turn, guides the formulation of R&D activities, which are specifically designed to bridge gaps between current capabilities and future needs.

The framework recognizes that R&D activities do not exist in isolation but are influenced by various organizational factors. These include production and technology capabilities, capacity building efforts, and related business functions. This holistic approach ensures that R&D initiatives are aligned with the broader organizational context and capabilities.

The ultimate goal of this process is the transformation of the organization into an RDIDE with a clear vision and defined targets. This transformation is realized through the development of a comprehensive R&D Blueprint (Barbosa et al., 2020; Mehand et al., 2018). The blueprint comprises eight key components: organizational overview and goals, current business operations analysis, business trend analysis, environmental analysis, scenario development, technology assessment, R&D and technology roadmap development, and a detailed R&D plan.

This approach emphasizes a holistic view of business and innovation, recognizing the interdependence of R&D with all aspects of the business and its environment. By linking business analysis, model development, and R&D activities, the framework ensures that innovation efforts are strategically aligned with overall business objectives and market realities.

The IRDCap framework provides a structured yet flexible approach for businesses to systematically develop their innovation capabilities. Its iterative and dynamic nature allows organizations to adapt to changing market conditions while maintaining a focused approach to R&D and innovation. This methodology is particularly valuable in dynamic market environments, where the ability to innovate and adapt quickly can be a key determinant of competitiveness and long-term success.

By providing a comprehensive roadmap for R&D and innovation, this framework addresses a critical need in Thailand's industrial sector, potentially contributing to the country's efforts to enhance its technological capabilities and economic competitiveness.
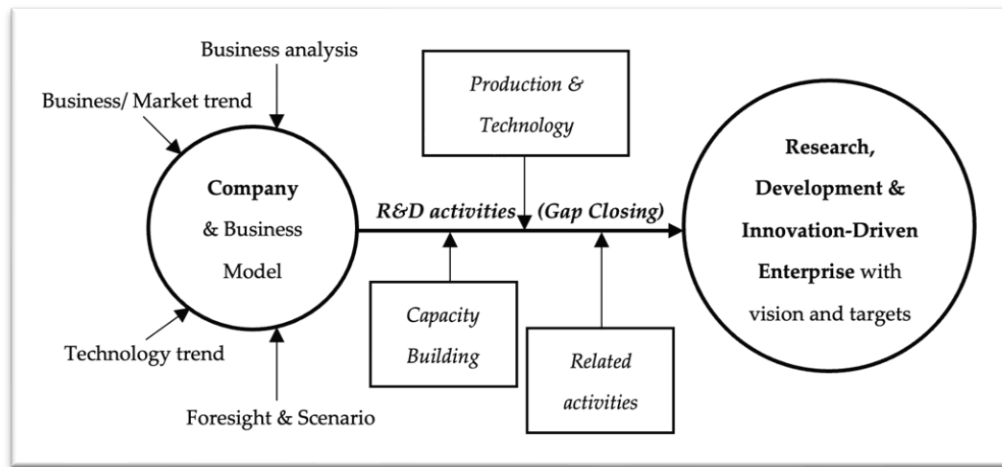
Figure 3. Conceptual Idea of IRDCap R&D Blueprint.

The R&D blueprint serves as a critical component of the IRDCap program, providing businesses with a strategic tool for systematic planning and execution of innovation and technology development initiatives. Figure 4. illustrates a simplified example of an R&D roadmap from a case study company, demonstrating a comprehensive temporal framework that integrates various organizational domains including R&D, production technology, human resources, and marketing. This multifaceted approach aligns with contemporary theories of innovation management, which emphasize the importance of cross-functional integration in driving organizational innovation. Additional key aspects that can be incorporated into such roadmaps include strategic alignment, technology roadmapping, resource allocation, collaboration strategies, market analysis, and Intel-lectual Property strategies.
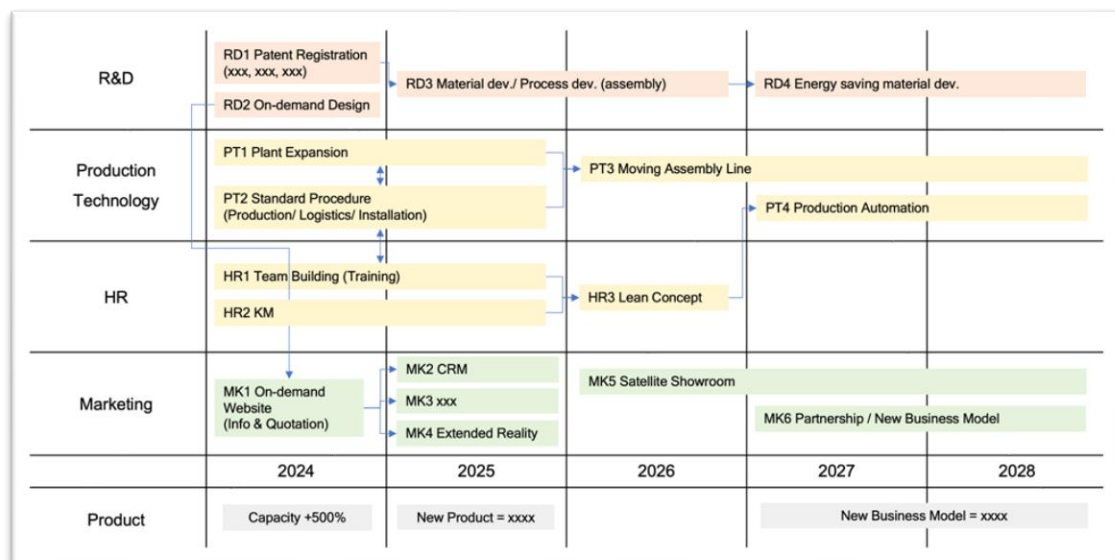
Figure 4. Simplified Example of R&D Roadmap.

Typically spanning a five-year horizon, the roadmap encompasses a range of activities designed to address specific organizational gaps, meet evolving needs, and propel the entity towards its strategic vision and objectives. Key elements often include patent registration, on-demand design capabilities, material and process development, energy-saving innovations, and production automation. These activities reflect the organization's commitment to technological advancement and operational efficiency, consistent with the resource-based view of competitive advantage.

A notable feature of the roadmap is its integration of human resource development initiatives, such as team building and knowledge management, alongside technological innovations. This holistic approach underscores the critical role of human capital in fostering innovation. The inclusion of a marketing track, featuring elements like CRM implementation and extended reality applications, demonstrates a customer-centric approach to innovation.

It is important to note that Figure 4. represents a simplified and partially redacted version of an actual organizational R&D roadmap, with certain details omitted due to confidentiality constraints and non-disclosure agreements. This practice of selective disclosure in academic research reflects the delicate balance between sharing knowledge and protecting proprietary information in industry-academia collaborations.

The roadmap's structure, with its clear delineation of activities, timelines, and cross-functional dependencies, exemplifies best practices in R&D management. It provides a visual representation of the organization's innovation strategy, facilitating alignment between various organizational units and supporting effective resource allocation, including budgeting. This strategic planning approach is crucial for enhancing an organization's innovative capabilities and maintaining competitive advantage in dynamic market environments.

Central Platform for IRDCap Consulting

The IRDCap Central Platform represents a sophisticated information system designed to facilitate monitoring and progress reporting in collaborative efforts between consultants and businesses. This multifaceted platform is built upon a robust architecture comprising three key components, each serving a specific function within the system's overall framework (see Figure 5).
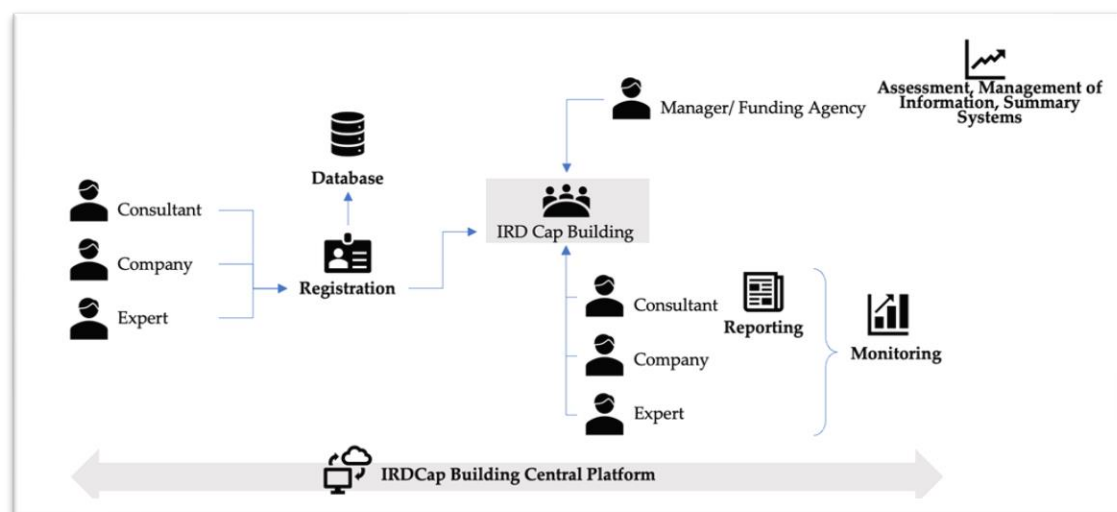
Figure 5. IRDCap Central Platform Ecosystem.

The first component utilizes JSON to create Rich Menus for Line@, a widely used communication application in Thailand (see Figure 6.). This implementation, accessible through an API, enables dynamic menu management based on user types within the system, enhancing user experience and functionality. The second component employs React as the framework for irdcap.com website development. Selected for its widespread acceptance in the developer community, React offers high flexibility in usage, reduces development time, and is supported by comprehensive documentation, facilitating efficient and effective web interface creation. The third component leverages MS SQL as the database management system, storing processed results in a format readily accessible for connection to Self Service BI systems or user-facing dashboards, ensuring data integrity and accessibility.

This integrated platform serves various critical functions within the consultancy framework. It acts as a central communication hub, enabling efficient information exchange among stakeholders, thereby fostering collaboration and knowledge sharing. The system provides self-monitoring capabilities for consultants, client companies, and project managers, allowing real-time performance tracking and progress assessment

(see Figure 7.). This feature enhances transparency and accountability within the project ecosystem, facilitating timely interventions and adjustments as needed.
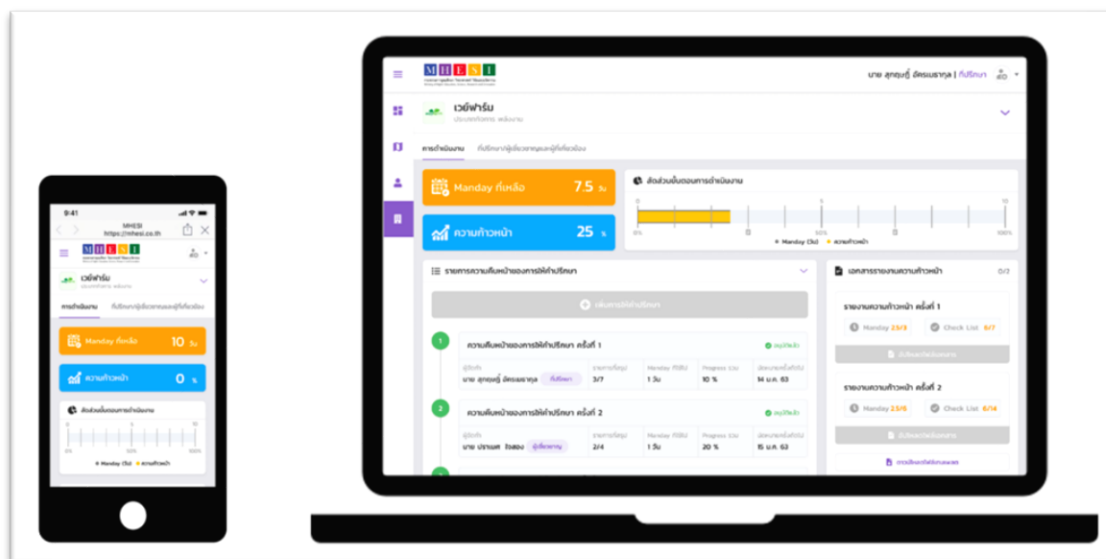

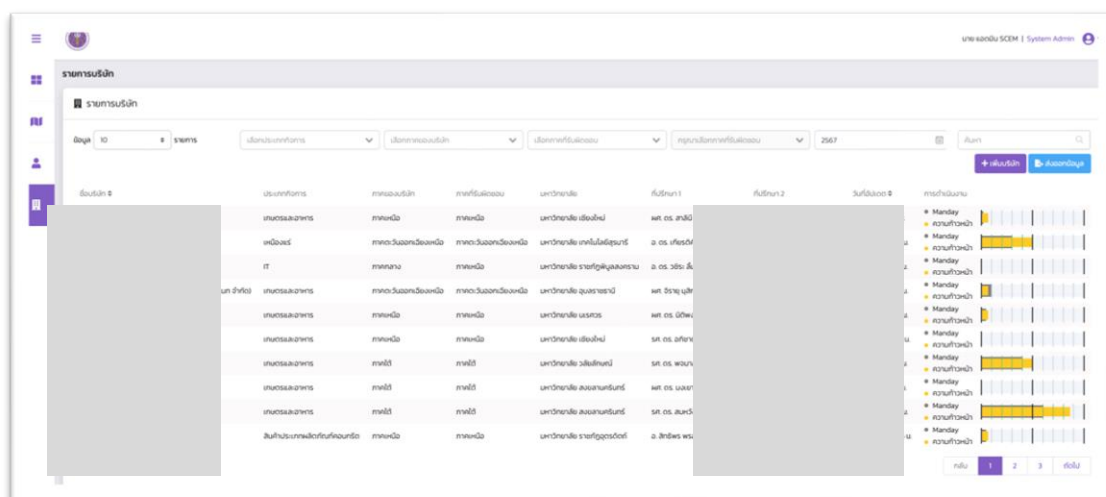*Figure 6.* IRDCap Central Platform on Line@ and irdcap.com

Figure 7. Company Database and Monitoring Status Bar

Furthermore, the platform offers comprehensive document management capabilities, supporting both upload and download of all pertinent reports. This functionality streamlines information flow and ensures that all stakeholders have access to up-to-date project documentation. A key feature of the platform is its hierarchical access control mechanism, which implements stringent information security measures through a tiered authorization structure. This structure aligns information visibility with individual roles and responsibilities within the project ecosystem, ensuring data confidentiality and integrity while promoting appropriate information sharing.

By integrating these diverse functionalities into a single, cohesive platform, the IRDCap Central Platform significantly enhances the efficiency and effectiveness of the consulting process, providing a robust technological foundation for the IRDCap initiative.

IRDCap Knowledge Exchange

Throughout the five-year duration of the IRDCap initiative, a series of knowledge exchange activities were systematically implemented to enhance the program's effectiveness and relevance. These activities were

designed to facilitate continuous improvement across all aspects of the program, adhering to the PDCA (Plan-Do-Check-Act) cycle principle.

A key component of this improvement process was the regular organization of learning exchange sessions among trainers who had completed the TTT program and subsequently gained experience in IRDCap Consulting. These sessions provided a valuable platform for sharing insights, challenges, and best practices derived from hands-on consulting experiences. Complementing these trainer-focused exchanges, feedback was also actively solicited from businesses that had received IRDCap Consulting services. This dual-perspective approach ensured a comprehensive understanding of the program's impact and areas for potential enhancement.

The feedback gathered through these channels informed iterative improvements to various aspects of the program. These included refinements to the TTT curriculum content, adjustments to the training duration and structure, and modifications to the training activities to ensure optimal effectiveness. Additionally, the IRDCap Consulting process and the IRDCap Central Platform underwent continuous evaluation and enhancement based on user experiences and identified needs.

Results and discussion

The IRDCap program has demonstrated significant success in bridging the gap between academic knowledge and practical business needs, while simultaneously revealing important insights about the challenges and dynamics of building R&D capacity in Thailand's industrial sector. Over its five-year implementation period, the program has established a substantial nationwide presence, conducting 12 TTT training sessions and producing 489 trainers, indicating successful scaling of the initiative's capacity-building component.

The program's engagement with 201 companies across diverse industries reveals interesting patterns in sectoral adoption of R&D initiatives. The strong concentration in the agriculture and food sector, accounting for approximately 70% of participants, reflects both Thailand's industrial strengths and the sector's readiness to embrace innovation. The cosmetics sector's emergence as the second-largest participant group (13%) suggests growing recognition of R&D's importance in high-value consumer products. The distribution across other sectors including construction, textiles, and IT indicates the program's broad applicability while highlighting potential areas for expanded outreach.

A critical success factor has been the establishment of dedicated R&D units across all 201 participating companies, complete with designated personnel who received comprehensive capacity building. However, this achievement revealed an important challenge: the misalignment between some businesses' expectations of quick wins and the program's emphasis on long-term strategic development. This tension highlights the need for clearer communication of program objectives and better expectation management during the initial engagement phase.

The program's economic impact has been substantial, generating a valuation of 241.2 million US dollars through value addition, cost savings, and market expansion. The catalyzation of 28.1 million US dollars in investment and creation of over 750 high-value employment positions demonstrates the program's role in driving economic development. These outcomes compare favorably with similar initiatives in other emerging economies, though direct comparisons are complicated by varying economic contexts and program scales.

The R&D Roadmap's effectiveness as a communication tool has emerged as a particularly valuable outcome, evidenced by several success stories. One notable case demonstrated its utility in facilitating long-term planning, market research, and open innovation initiatives, resulting in doubled sales within two years and multiple innovation awards. Another case highlighted its role in attracting Stock Exchange investors, showcasing the roadmap's versatility in different business contexts. However, the implementation process revealed the crucial importance of sustained executive engagement, as successful roadmap execution consistently correlated with strong leadership buy-in.

The program's sustainability aspects present both opportunities and challenges. Many participating companies have successfully leveraged their IRDCap experience to access additional funding and expand their involvement in the open innovation ecosystem. This suggests the program serves as an effective

catalyst for ongoing innovation and collaboration. However, the dynamic nature of the business and technological environment necessitates regular roadmap revisions, with annual updates recommended to maintain alignment with evolving market conditions and technological advances.

Several limitations and areas for future development have been identified through the implementation process. First, the program's heavy reliance on government funding raises questions about long-term sustainability and the need for alternative funding models. Second, while the program has been successful in establishing R&D units, measuring their long-term effectiveness and sustainability requires continued monitoring beyond the initial implementation phase. Finally, the varying levels of digital readiness among participating companies affected their ability to fully utilize the IRDCap Central Platform, suggesting the need for additional support in digital transformation.

These findings collectively emphasize the complex, multifaceted nature of building R&D capacity in industrial settings. They highlight the need for flexible, adaptive approaches that can balance immediate business needs with long-term strategic objectives while fostering a culture of continuous innovation and collaboration within the broader innovation ecosystem. Future research could focus on longitudinal studies of participating companies to better understand the long-term impacts of the program and identify factors contributing to sustained R&D success in Thailand's industrial context.

Conclusion

The Industrial Research and Development Capacity Building (IRDCap) initiative represents a significant and innovative approach to enhancing Thailand's research and development capabilities. Through its comprehensive framework encompassing both training and consulting components, IRDCap has demonstrated a successful model for bridging the gap between academic knowledge and industrial application.

The program's multi-faceted approach, incorporating the Train-the-Trainer (TTT) project and IRDCap Consulting, has proven effective in developing a robust ecosystem of R&D expertise. The TTT project has successfully cultivated a cadre of skilled trainers, while the consulting component has provided tailored support to a diverse range of businesses. This dual approach has enabled the program to address both the supply and demand sides of R&D capacity building, contributing to a more holistic enhancement of Thailand's innovation landscape.

The quantifiable impacts of the IRDCap program, including substantial economic value generation, investment stimulation, and job creation, underscore its effectiveness in translating enhanced R&D capabilities into tangible economic outcomes. Moreover, the program's strong focus on the agriculture and food sector aligns well with Thailand's economic strengths and priorities, potentially contributing to increased competitiveness in these critical industries.

The R&D Roadmap developed through IRDCap has emerged as a particularly valuable tool, serving not only as a strategic planning instrument but also as an effective communication medium for organizations. Its demonstrated utility in facilitating long-term planning, attracting investment, and driving innovation provides strong evidence of the program's practical relevance and impact.

Acknowledgments

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