Readiness Assessment for IDE Startups: A Pathway toward Sustainable Growth

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Abstract: Innovation-driven enterprises (IDEs) steer their businesses with ideas, technology, and innovation. However, many of them have limited resources, capabilities, and readiness to turn their valuable creativity into marketable products. For IDE startups to survive and achieve sustainable growth, they must seek financial and other, non-pecuniary support from governmental agencies and large corporate venture capitalists. Usually, governments and large firms need to determine the readiness level (RL) of IDE startups, in order to set up proper strategies for resource allocation, resource prioritization, and collaborative R&D to support startups. In addition, IDE startups themselves also need to perform self-assessment of their readiness level to identify rooms for improvement. This research addresses the significance of IDE readiness assessment. An assessment framework, connecting four dimensions, specifically technology, manufacturing, business, and commerce, is proposed, and three case examples are presented to demonstrate the application of the proposed framework.

Keywords: readiness level; innovation-driven enterprises (IDEs); IDE startups; technology; innovation; business ecosystem

1. Introduction

In the era of the innovation-centered economy, IDE startups play key roles in national innovation development, as the source of ideas, creativity, technology, and innovation. However, some IDE startups cannot sustainably compete, due to their limited capabilities. IDE startups may be capable for the exploitation of new technologies and turn into innovation, but being a newly established business, IDE startups may face challenges in penetrating the markets, limited financial capitals, lack of experiences in running a business, managing an organization, etc. Therefore, it would be useful for IDE startups to monitor the stage of their development and identify room for further improvement, in order to strategically develop their capabilities aligning among technology, manufacturing, commercial, and business, as required in each stage.

In many countries, governmental agencies attempt to support IDE startups with various measures, ranging from supplying funds and resources and developing a business ecosystem to create connections to issuing tax reduction policies to sponsor corporate venture capitalists. Meanwhile, some large firms are willing to facilitate IDE startups with expectations to access new ideas and new business opportunities. Nevertheless, supporting governmental agencies and facilitating firms need to know what kind (and in what degree) of support they should provide to IDE startups. Hence, the assessment of IDEs’ readiness becomes necessary. Based on literature review, the readiness level (RL) can be assessed in four dimensions of technology, manufacturing, commercial, and business (see details in Sections 2 and 5). The readiness assessment results can be used as a guideline for achieving the effectiveness of IDE startups support.

This research highlights the significance of the readiness assessment and answers three research questions: (1) how can a framework for assessing the readiness of IDE startups be developed; (2) how can this assessment tool be used; and (3) how can the assessment
results be applied? These questions motivate this research to introduce an analytical framework for developing the assessment tool. The scope of the readiness assessment tool for IDE startups consists of four dimensions: technology readiness, manufacturing readiness, commercial readiness, and business readiness. As a methodology, this research employs qualitative research, with three data collection techniques: in-depth interviews, focus group discussions, and a review of the relevant literature. Primary data were collected from two groups: (1) governmental agencies that support innovation development and (2) IDE startups.

Responding to the three research questions, this paper starts with a review of the background and applications of readiness levels (RLs) from the relevant literature and presents the development of the readiness assessment framework for IDE startups. The next section provides cases demonstrating how the proposed assessment framework can be applied. Then, the final section provides managerial implications, regarding the strategic implementation of the assessment framework.

2. Readiness Levels (RLs): Background and Application

This section provides an overview of readiness level (RL) applications. A company’s readiness level can be defined by adopting the concept of the maturity model, which refers to the status of transition that classifies phases of growth and maturity [1]. The concept of this model originated from the demand for quality management, resulting in the “Quality Management Maturity Grid” [2]. Later, the specific purpose of improving the maturity of technology led to the development of the technology readiness level [TRL]. The RL has been used extensively, since it is capable of creating clear communication and a common understanding of technology, manufacturing, commerce, and business, in terms of development levels, elements, and relevant risks [3]. The RL is also applied for evaluating investment attraction by analyzing the TRL, coupled with the risk level. Moreover, the RL has been widely applied among diverse actors within an innovation ecosystem, including industrial firms, startups, or even entrepreneurial scientists, who are aiming for research commercialization [4]. Once policy makers or business managers initiate an innovation-oriented vision and missions, the involved teams are responsible for developing a strategic plan and determining the level of readiness, as well as risks associated with the plan [5]. Thus, the precise readiness assessment, covering both technology and non-technology dimensions, could make the strategic plan more realistic.

In the US, the TRL has been used as a communication tool for research funding and research extensions. It can also be used for a variety of other purposes, such as technology management and technology transfer. The United States Department of Defense (DoD) integrated the TRL with the DOD 5000 framework, resulting in the technology programming management model (TPMM) [6,7] and applications for risk analysis [8]. Moreover, the NIIMBL project, as part of the Manufacturing USA network, used the manufacturing readiness level (MRL), developed by the United States DoD, for the selection of project funding, with the aim of accelerating biological innovation and filling the gap in manufacturing innovation among the government, universities, and industries that exists between MRL 4 (i.e. technology produced in a lab environment) and MRL 7 (i.e. technology produced in a representative environment) [9].

In Canada and the UK, governmental agencies have adopted the TRL as a criterion for considering research funding and budgets, as well as for sourcing technology and innovation from foreign countries. In Canada, a mentor works as a central unit, advising on funding [10], while, in the UK, the Engineering and Physical Sciences Research Council plays an advisory role in issues of research funding, development, technology, and innovation. Moreover, the council promotes and supports the establishment of technology and innovation development networks [11].

In the European Union countries, the RL assessment tool has been used for determining funding research, as well as evaluating and analyzing barriers affecting technology development. For instance, Nano Com applied the RL to marketing, manufacturing,
technology, and investment to detect impediments in each phase [12]. Technology and manufacturing are essential when the TRL is lower, whereas marketing and strategies become more important when the TRL is higher.

In Australia, the TRL framework has been integrated and used with the commercial readiness index (CRI) or commercial readiness level (CRL) to assess the efficiency of policies supporting enterprises in an energy sector [13]. Moreover, the TRL has been used to communicate policies, to create understanding and prepare business incubators.

In South Korea, agencies support IDEs by making connections for funding, ensuring credit, assessing technology, investing equity securities, and transferring technology, with the aim of improving the accessibility to funding for IDEs [14]. For instance, Korea Technology Finance Corporation (KOTEC or KIBO) is responsible for supporting commercial alliances and recommending sources of low-interest funds [15]. KOTEC (or KIBO) uses the TRL in risk evaluation and technology valuation [16]. It ranks the risks of technology from the lowest level, AAA, to the highest level, D, by applying an analytical hierarchy process (AHP). Additionally, KOTEC evaluates and analyzes the RLs of technology, marketing, commerce, and factors affecting the economy.

In the case of China, the group of technology, R&D, and investments, regarding science, technology, and innovation, can be divided into three big clusters: (1) a basic research cluster; (2) an applied research cluster; and (3) a development for applications cluster [17]. Moreover, in Taiwan, the Ministry of Science and Technology (MOST) and Department of Industrial Technology (DoIT) of the Ministry of Economic Affairs (MOEA) have jointly established an agency, namely the Industrial Technology Research Institute (ITRI), to provide resources for the development of science, technology, and innovation [18]. The DoIT is responsible for applying MOST’s research to develop marketable products.

In summary, the concept of RL has been widely applied in various dimensions, i.e., technology, marketing, manufacturing, commercial, and investment. Table 1 below compares the RL applications used in different organizations.

| Facilitating Organization (Country) [Source] | Dimension of Readiness | Target Organizations | Purpose of Assessment |
|---------------------------------------------|------------------------|----------------------|-----------------------|
| US Government Accountability Office (GAO) (U.S.A.) [7] | Technology Readiness | Federal agencies | To evaluate the maturity of technologies, in order to make decisions on acquisition programs and projects. |
| The United States Department of Defense (DoD) [8] | Technology Readiness | Industries | To apply for risk analysis. |
| The NIIMBL project, as part of the Manufacturing USA network (U.S.A.) [9] | Manufacturing Readiness | Government, universities and industries | To support project funding for accelerating biological innovation and fill the gap in manufacturing innovation among target organizations. |
| Governmental agencies (Canada) [10] | Technology Readiness | Industrial firms | To support mentoring on research funding and budget. |
| The Engineering and Physical Sciences Research Council (U.K.) [11] | Technology Readiness | Organizations in technology and innovation networks | To support advisory roles in issues of research funding, technology, and innovation development, as well as to promote technology and innovation networks. |
| Nano Com (the EU countries) [12] | Marketing, manufacturing, technology and investment Readiness | Industrial companies | To detect barriers in marketing, manufacturing, technology, and investment. |
| The Australian Renewable Energy Agency (ARENA) (Australia) [13] | Commercial (namely Commercial Readiness Index) | Industrial companies | To evaluate commercial readiness in renewable energy technology. |
According to Table 1, the dimensions of readiness have been expanded to cover various aspects, including technology, marketing, manufacturing, commerce, or business. It depends on the assessment objective. Additionally, the readiness assessment has been mostly used by governmental agencies, whereas evidence on the use of readiness assessment for IDE startups is scarce. Hence, this research expects to propose the RL assessment tool which integrates necessary dimensions. The next section will describe how the RL assessment tool was developed and how the validity of the tool was tested.

3. Research Methodology: Development and Validity

This research aimed to answer three questions, specifically (1) how can a framework for assessing the readiness of IDE startups be developed; (2) how can this assessment tool be used; and (3) how can the assessment results be applied? This research intended to produce a readiness assessment framework and demonstrate its application to IDE startups. Basically, qualitative methods are often used to explore perspectives and experiences from the participants’ standpoints [19]. Thus, the qualitative research methodology was employed to investigate the applications of the RL in four dimensions: the technology readiness level (TRL), manufacturing readiness level (MRL), commercial readiness level (CRL), and business readiness level (BRL). The data pertaining to those four dimensions were collected from the relevant literature. Moreover, in-depth interviews and focus group discussions, with key players in the business ecosystem of IDE startups, were conducted. Next, the collected data were integrated to design the readiness assessment framework and develop the readiness assessment tool. Consultations with experts and key players were also carried out, in order to affirm the content validity and applicability of the assessment tool. The descriptions are presented below.

3.1. Preparing Questions for Interviews and Focus Group Discussions

This research investigated RL applications in various countries using the relevant literature. The secondary data sources included accessible academic papers and details of innovation funding projects. The information obtained was then used to outline open-ended questions for in-depth interviews and focus group discussions (see Appendix A for examples of the questions).

3.2. Conducting In-Depth Interviews

In-depth interviews were held to obtain insights into RL applications from key players’ perspectives. The interviews were conducted in two rounds: the first with governmental agencies that support IDE startups and second with IDE startups. Before the interviews, the informants were asked permission to make voice recordings, and their agreement was obtained. The informants were encouraged to answer open-ended questions and give recommendations for RL applications.
3.3. Designing the Readiness Assessment Framework

Once the interviews had been conducted, quotations were transcribed, extracted, and analyzed by using indexing category. Then, the analyzed quotations were used to design the readiness assessment framework, which contains definitions of each level, element, and indicator of readiness in various dimensions. The readiness assessment framework will be presented in Section 4.

3.4. Testing the Content Validity of the RL Framework

To ensure the content validity, the readiness assessment framework designed was reviewed and approved by content experts.

3.5. Conducting Focus Group Discussions and Developing the Readiness Assessment Tool

Focus group discussions were organized to obtain insights into the application of the RL, with the aim of developing the assessment tool further. The discussions were arranged in the form of brainstorming activity, along with the “Policy Design Lab” concept during November 2018. The participants were 60 personnel involved in the business ecosystem of IDE startups from governmental agencies, large technology-intensive firms, and IDE startups. The discussions consisted of two sessions. During the first session, the readiness assessment framework designed earlier was presented, and the participants were encouraged to comment on this framework. In the second session, the participants were divided into six groups, each comprised of members from governmental agencies, large technology-based firms, and IDE startups. All six groups were motivated to brainstorm ideas on how to apply the readiness assessment framework. Once the discussions had ended, quotations were transcribed, extracted, and analyzed. Then, those analyzed quotations were used to develop the readiness assessment tool (see the descriptions in Section 4).

3.6. Testing the Applicability of the Readiness Assessment Tool

To affirm the applicability, the readiness assessment tool was tested. The test was performed by professionals from the three areas of business, technology, and innovation to confirm the coherence of professionals’ analysis, regarding the clarity of objectives and details, as well as the usability of the tool. Once the consistency of the professionals’ analysis had been achieved, the readiness assessment tool was concluded and rediscussed with the professionals. As the results, recommendations for the proper application of this tool to IDE startups were obtained (see the case demonstration in Section 5).

In summary, the insights from the relevant literature and in-depth interviews yielded the readiness assessment framework, whereas the results from the focus groups led to conclusions on the readiness assessment tool, containing four dimensions, along with their descriptions, parameters, and measurement indicators. The readiness assessment framework and readiness assessment tool were validated by content experts. However, the scales developed in this research may have to be adjusted in the future, as different circumstances may arise, and the role of key players in the IDE startups business ecosystem may have to change over time. Consequently, the validity of the findings might have to be revisited from time to time to adapt to the changing business environment.

4. The Development of the Readiness Assessment Framework

Once the research methodology, as described earlier, had been accomplished, the findings revealed that the technology readiness level (TRL) dimension acted as a reference for the development of other dimensions of the readiness assessment tool: the manufacturing readiness level (MRL), commercial readiness level (CRL), and business readiness level (BRL). The descriptions of the development of IDEs toward sustainable growth were defined and classified into five stages, as shown in Table 2 below.
Table 2. Five stages: a pathway toward sustainable growth of IDE startups.

| Stage | Description |
|-------|-------------|
| Stage 5: Sustain | The enterprise is moving toward sustainable growth and envisions becoming the industry leader. New or existing product development is continually being planned. |
| Stage 4: Commercialize | The enterprise has achieved product development and market expansion. Upscaling for business growth is being planned and requires additional monetary support. Financing is also concentrated. |
| Stage 3: Develop & Test | The enterprise has undertaken development and testing efforts. The usability of the product has been confirmed. The supply chain and distribution efforts are being managed. |
| Stage 2: Prototype | The enterprise has developed the product concept, reinforced with technological feasibility. Business registration has been achieved. However, prototyping is still being processed. The enterprise is stepping up its development and testing efforts. |
| Stage 1: Conceptualize | The enterprise has been established. The product concept has been designed, but the technological feasibility is continually being planned. Financing is also concentrated. |

The five stages above were used as the main structure of the readiness levels in all four dimensions (see Figure 1 below).

![Figure 1](image-url)
As Figure 1 (above) shows, the descriptions of the RLs in all four dimensions have been carefully aligned. As a result, a certain RL in one dimension was considered to be coherent with another stage in other dimensions; for example, stage 1 Conceptualize spans TRL 1–3, MRL 1–2, CRL 1, and BRL 1–2. The resulting readiness assessment framework was then used as the outline for developing the readiness assessment tool. This readiness assessment tool consists of two materials: a (1) self-assessment form and (2) assessment form for business professionals and innovation management. To develop the tool, the sub-elements of each level were converted into a series of questions and a list of empirical evidence required to support the answers.

5. The Description of the Readiness Assessment Framework for IDE Startups

As mentioned earlier, the readiness assessment framework consists of four dimensions to be employed in the assessment tool for IDE startups. They are the technology readiness level (TRL), manufacturing readiness level (MRL), commercial readiness level (CRL), and business readiness level (BRL). This paper conducted a review of the relevant literature, in an attempt to obtain an understanding of and make linkages among the RLs and four dimensions. The resulting descriptions are presented below.

5.1. Dimension 1: Technology Readiness Level (TRL)

The TRL evaluates the advancement of technology by using the necessary indicators to classify the nine levels of technology readiness, from the concept generation to the application in real circumstances [20–23]. The details of each readiness level are presented in Figure 1. The lowest level, TRL 1, represents the readiness to study, discover, and set basic assumptions. TRL 2 indicates the readiness to create technology concepts and/or apply technology formulas. TRL 3 represents the readiness to analyze and experiment with core functions and/or prove the concept’s elements. TRL 4 means that important elements have been demonstrated in laboratories, while TRL 5 refers to those that have been shown in relevant circumstances. TRL 6 represents the readiness to test the models of the core system and subsystems or models in relevant circumstances. TRL 7 refers to the readiness to test a prototype in the field, and TRL 8 is achieved when the field prototype has been certified. The highest TRL, TRL 9, means that products are ready to be delivered and used. By connecting with the definitions of the RLs, TRL 9 presents stage 3 development and testing of the proposed readiness assessment framework.

5.2. Manufacturing Readiness Level (MRL)

The manufacturing readiness level (MRL) was designed by the United States Department of Defense (DOD), with the purposes of assessing the readiness levels of manufacturing and identifying existing system risks [9]. Generally, the manufacturing process cannot be assessed until the manufacturing technology and prototype are stable. Hence, the MRL should be used in conjunction with the TRL. In Figure 1, MRL 1 to MRL 8 are organized in accordance with the TRL’s nine levels. Additionally, MRL 9 and MRL 10 are associated with a lean system and ongoing improvement of the manufacturing process. By connecting with the definitions of the RLs, MRL 9 and MRL 10, thus, equate to stage 4: commercialize.

5.3. Dimension 3: Commercial Readiness Level (CRL)

The commercial readiness level (CRL) portrays the development of marketing efforts, for example, introducing products to target markets, measuring consumers’ price sensitivity, and accessing new markets [12,24]. The Australian Renewable Energy Agency (ARENA) developed the commercial readiness index (CRI) and applied it to renewable energy technology [13]. The CRI developed by ARENA contains six levels, from CRI 1 Hypothetical Commercial Proposition (which links with TRL 2) to CRI 6 Bankable Asset Class. The key indicators include regulations, stakeholders’ acknowledgment, academic information, cost, revenue, supply chain skill, marketing opportunities, and company growth.
Generally, commercial readiness cannot be assessed until the necessary quantity, product standard, and production capability have been achieved. Hence, the CRLs should be used in combination with the MRL. From CRL 1–9 (see Figure 1), CRL levels 1–8 were organized in accordance with the 10 MRLs. In addition, the highest level, CRL 9, is associated with business growth, resulting from effective commercialization. From the definitions of the RLs, the highest CRL, CRL 9, relates to stage 5: sustain.

5.4. Dimension 4: Business Readiness Level (BRL)

The business readiness level (BRL) indicates the development of efforts in management, for example the business model, capital, business concept, business strategy, cash flow, business establishment, and teamwork management, with the purposes of fixing problems within firms and growing their business toward sustainability. This research designed and developed the nine-level BRL by applying the concept of venture investment readiness & awareness levels (VIRAL). VIRAL was developed by Ross Baird and Bidisha Bhattacharyya of Village Capital [25] with the aim of assessing corporations’ readiness, from the business concept and growth to corporate expansion through an initial public offering (IPO) or by merging with other large firms. The VIRAL framework was drawn from NASA’s TRL, with the two objectives of providing clear classifications and creating a common understanding among entrepreneurs and investors. Since VIRAL explicitly identifies key steps, including the team, product, and business format, entrepreneurs are able to see the entire system and identify the level of investors that they should contact. Nowadays, VIRAL is widely used among startups.

Generally, business readiness cannot be assessed until the upscaling process, competitive advantages, and business growth have been achieved. Hence, the BRL should be used in combination with the CRL. As Figure 1 shows, BRL levels 1–9 were organized in accordance with the CRL’s nine levels. Additionally, the highest level, BRL 10, is associated with moving toward sustainable growth, and the vision of becoming an industry leader. By linking with the definitions of RLs, BRL 10 meets stage 5: sustain.

The RL assessment framework and the model were then delivered to experts to approve the content validity. The result of the validity test was satisfactory, and approval was gained. Next, the framework and the model were presented in group discussions for further development of the RL assessment tool. As a result, the analyzed quotations from the discussions were used to create assessment items. Then, the assessment tool was tested with real cases to ensure applicability. The demonstration of cases is presented in the next section.

6. Case Demonstration of the Application of the Readiness Assessment Tool for IDEs

This paper tested the applicability of the readiness assessment tool with three IDE startups, namely Company A, Company B, and Company C. The demonstration will be presented in three parts: the (1) company background; (2) readiness assessment results; and (3) readiness improvements. Boxes 1–3 below contain the case descriptions (the cases are based on the actual organizations, but their names have not been disclosed), which include four parts: the (I) business background; (II) development path; (III) results of readiness assessment over time; and (IV) reflections from the management on the company’s development and improvement over time.

Box 1. Case description of Company A.

Case 1: Company A
I. Business Background
Company A innovates in the biotechnology sector and develops non-toxic, environment-friendly products (e.g., fertilizer and vaccines) for crops. Nowadays, Company A receives financial support from venture capitalists and accesses both domestic and international markets.
II. Development Path
Year 2002—when the prohibition of the use of antibiotics and chemicals for prawns was issued as a non-tariff barrier in the global market, Company A presumed that this regulation would also soon be enforced for crops. Hence, the company initiated the development of non-toxic products for crops. In general, the entire fertilizer and pesticide market (both organic and inorganic) faced intensive competition. However, within the market of organic fertilizers and pesticides, the competition of organic fertilizers/pesticides was not as fierce. During the first 5 years, Company A collected relevant research from two leading domestic universities. Then, it developed a prototype (funding supported by governmental agency and conducted further research at Biotech).

Year 2010—Company A focused on R&D in farming and established a small factory of fertilizers and vaccines for crops. The company turned its prototypes into marketable products, with the help from an agriculture specialized local university. Company A also sought the knowledge in the field of plant physiology with another local institute, through the support from technology assistance program and co-developed marketable products, with consultants from various universities. Later, Company A realized the importance of increasing its capital for business growth. Consequently, the company started raising funds from relatives and expanded its production capacity.

Year 2013—Company A set up an official marketing team. As a result, it could expand its market both domestically and internationally.

Year 2016—Venture capitalists co-invested with Company A to the amount of 1 million baht.

Nowadays, Company A’s factory can customize products to correspond to the needs of customers by adjusting the production line in a very short period of time. The proportions of business in the domestic market and the foreign (ASEAN) market are 80% and 20%, respectively. Moreover, the company is currently seeking to undertake an initial public offering (IPO) in the market for alternative investment (MAI) stock market.

III. The Results of Readiness Assessment Over Time
The readiness assessment results are shown in the two forms of numbers and a radar chart below:

|         | 2009 | 2012 | 2015 | 2019 |
|---------|------|------|------|------|
| TRL     | 7    | 9    | 9    | 9    |
| MRL     | 4    | 5    | 7    | 10   |
| CRL     | 2    | 4    | 5    | 7    |
| BRL     | 2    | 4    | 5    | 6    |

IV. Reflections from the Management on the Company’s Development and Improvement Over Time
The Improvements of the Technology Readiness Level (TRL)
TRL 7: The product prototype has passed the initial test.
TRL 7 → TRL 9: Improve the prototype and design products for commercialization.

The Improvements of the Manufacturing Readiness Level (MRL)
MRL 4: The manufacturing prototype has passed the test, and the essential factors for production have been identified.
MRL 4 → MRL 5: Researchers support the design of the manufacturing process for a small production volume.
MRL 5 → MRL 7: The manufacturing capacity has been expanded by moving production sites from ordinary commercial buildings to a factory.
MRL 7 → MRL 10: The manufacturing expertise is sufficient for the company to respond agilely to the demand of the market.

The Improvements of the Commercial Readiness Level (CRL)
CRL 2: The first target market base, shrimp keepers, has been obtained.
CRL 2 → CRL 4: The target market, distribution channels, and a reasonable price have been analyzed.
CRL 4 → CRL 5: The test results of the market acceptance and marketing concept have met expectations.
CRL 5 → CRL 7: A continual attempt to penetrate new markets has been realized.

The Improvements of the Business Readiness Level (BRL)
BRL 2: Business opportunities have been captured through the realization of quality shrimp farming and an attractive market price.
Box 1. Cont.

BRL 2 → BRL 4: Commercialized products have been used to test the assumptions of the business models and determine the necessary cost.
BRL 4 → BRL 5: Funds have been raised from relatives for business growth.
BRL 5 → BRL 6: A venture capitalist has invested 100 million baht in the company. The corporate structure and operating process have been re-engineered.

Box 2. Case description of Company B.

Case 2: Company B

I. Business Background
Company B initiated the application to support queue management for shops and restaurants. The company also designs solutions for hospitals and banks. Moreover, the company is expanding its business to Asian countries, like Malaysia, Vietnam, and Japan.

II. Development Path
Initially, Company B’s founders ran a software business but encountered difficulties in scaling up the company.
Year 2013—The founders were seeking better business opportunities.
Year 2014—The founders started to design the business model regarding a queuing solution.
Year 2015—The company registered as a startup firm named Company B and gained a large client base from restaurant chains. Moreover, Company B joined the startup competition and won the popular vote prize.
Year 2016—Company B gained an important deal with one of the giant restaurant chains. Apart from that, it broadened its business to developing a queuing system for banks. Furthermore, Company B expanded its business to Malaysia and gained up to 400,000 downloads.
Year 2018—Company B designed a smart hospital solution for large hospitals and expanded its business into Vietnam. The company started to test its delivery system and gained up to 1 million downloads during that year.

III. The Results of Readiness Assessment over Time
The readiness assessment results are shown in the two forms of numbers and a radar chart below:

| Year | TRL | MRL | CRL | BRL |
|------|-----|-----|-----|-----|
| 2014 | 9   | 10  | 2   | 2   |
| 2015 | 9   | 10  | 5   | 5   |
| 2017 | 9   | 10  | 8   | 5   |
| 2019 | 9   | 10  | 9   | 6   |

IV. Reflections from the Management on the Company’s Development and Improvement over Time

Technology Readiness Level (TRL)
TRL 9: The technology is ready for use by integrating elements from ready-to-use technology.

Manufacturing Readiness Level (MRL)
MRL 10: Due to operating on the cloud, the company can increase or decrease its production, without affecting its quality and costs.

Commercial Readiness Level (CRL)
CRL 2: The initial target market was stated, and the company initiated the concept of a mobile application for a queuing system for banks. However, the company shifted its direction toward an application for chain restaurant businesses, due to the higher frequency of reservations.
CRL 2 → CRL 5: A market test was performed, and Company B gained up to 50k downloads.
Box 2. Cont.

CRL 5  \rightarrow  \text{CRL 8}: \text{Company B expanded its business to foreign markets, starting with Malaysia in 2016.}
CRL 8  \rightarrow  \text{CRL 9}: \text{Company B applied its core capabilities to other domains, for example restaurant chains, banks, hospitals, and other services that require a reservation.}

\text{Business Readiness Level (BRL)}

\text{BRL 2: The company started to develop a business plan and test the product concept.}
\text{BRL 2  \rightarrow  \text{BRL 5}: The company improved the products and reinforced the team, as well as preparing for the required investment funding by entering many competitions.}
\text{BRL 5  \rightarrow  \text{BRL 6}: The company prepared for the necessary investment, so that the working capital was sufficient.}

Box 3. Case description of Company C.

\text{Case 3: Company C}

\text{I. Business Background}
Company C develops pneumatic wind-powered dental chairs and gains high sales of up to 20–40 million baht per year. The company also applies its technology to developing other clean energy products and air conditioners.

\text{II. Development Path}
Year 2006—A pneumatic wind-powered dental chair was researched and developed. Later, it became a marketable product and was displayed at a trade show held by the local professional association.
Year 2011—Major flooding in Thailand ruined most of the imported electric dental chairs, but the wind-powered ones were not destroyed and still functioned. Through a word-of-mouth phenomenon, the wind-powered dental chairs of Company C gained high popularity among customers and achieved dramatically higher sales, up to 20–40 million baht per year.
Year 2012—Company C won the best international innovation award in South Korea.
Year 2014—Company C achieved ISO 9001 and ISO 13485 certification. Moreover, the national technology center participated in collaborative R&D with Company C to create new products, for example, a dental chair for the disabled and elderly, as well as a pneumatic wind-powered mobile dental car.
Year 2015—The products of Company C were listed in the national government procurement product list. Company C had more than 100 domestic and foreign distributors.
Present—Company C applied its existing technological know-how to extend its business to clean energy products and air conditioners.

\text{III. The Results of Readiness Assessment over Time}

|          | 2006 | 2013 | 2016 | 2019 |
|----------|------|------|------|------|
| TRL      | 9    | 9    | 9    | 9    |
| MRL      | 7    | 9    | 9    | 10   |
| CRL      | 7    | 7    | 8    | 9    |
| BRL      | 3    | 5    | 6    | 7    |

IV. Reflections from the Management on the Company’s Development and Improvement over Time

\text{Technology Readiness Level (TRL)}
TRL 9: The first product of Company C, a wind-powered dental chair, passed the test process and was ready to use. It has been relentlessly developed and improved, until today.

\text{Manufacturing Readiness Level (MRL)}
MRL 7: Company C conducted an on-site manufacturing test and adopted a clear risk management policy.
Box 3. Cont.

| MRL 7 → MRL 9: Company C received industrial standard certification. |
| MRL 9 → MRL 10: Company C is able to adjust its manufacturing capacity to correspond to the domestic demand. Moreover, it has overseas factories to serve the foreign market. |
| **Commercial Readiness Level (CRL)** |
| CRL 7: Company C started selling its products to 10 dental clinics in Thailand. |
| CRL 7 → CRL 8: Company C received several compliments and product recommendations. Consequently, its reputation facilitated its penetration of foreign markets in 2014. |
| CRL 8 → CRL 9: Company C applied its technology to other commercialized products, including clean energy goods and air conditioners. |
| **Business Readiness Level (BRL)** |
| BRL 3: The company has its own target market, but the definition is still unclear. |
| BRL 3 → BRL 5: The company achieved dramatically higher sales after Thailand’s big flood in 2011. |
| BRL 5 → BRL 6: The company prepared for effective product development and supply chain management, so that it was able to operate as planned. |
| BRL 6 → BRL 7: The company’s wind-powered dental chair was listed in the national government procurement product list and gained revenue of more than 100 million baht. |

In summary, the demonstration of the three cases above reveals that the descriptions of the RLs in the four dimensions are coherent with real situations.

7. Discussion: Managerial Implications

IDE startups may be capable for the exploitation of new technologies and turn into innovation, but, being a newly established business, IDE startups may face challenges in penetrating the markets, limited financial capitals, lack of experiences in running a business, managing an organization, etc. This section discusses the managerial implications of the research findings for three types of key players in the business ecosystem of IDE startups: IDE startups, the government, and corporate venture capitalists. The descriptions follow.

Firstly, IDE startups can use the proposed tool as a self-assessment tool for monitoring their current status and identifying room for further improvements. Since this readiness assessment tool covers four dimensions (i.e., technology, manufacturing, business, and commerce), personnel from different functional units within an IDE startup should assess the readiness together. Therefore, the readiness assessment tool will function as an internal communication channel for creating a mutual understanding of the current readiness levels and aligning the objectives across units for further development [26]. With clear communication, it would allow the management to drive organizational changes effectively [27,28]. Moreover, IDE startups can use the assessment results as a guideline for preparing commercialization, short- and long-term development plans, as well as the business model for sustainable growth. The guideline can be presented as a roadmap, either for product-technology development or for organizational development [29–31]. The RL assessment tool also urges IDE startups to identify (and prioritize) what they need from other sponsoring parties in the business ecosystem. For example, IDE startups at CRL 5 (i.e., ones that already have products with customer acceptance) need to achieve MRL 7 (i.e., demanding the test of real manufacturing). Hence, they need the support of manufacturing sites, preparations for risk assessment, and the study of adjustable manufacturing approaches.

Secondly, governmental units play significant roles in the development of IDE startups in the business ecosystem [32]. Nowadays, IDE startups still need governmental support in various forms, for example funding, connecting to business networks and communities, and developing specialties in particular areas. Moreover, the government should motivate corporate venture capitalists to become involved in the development of IDE startups through various measures, such as reducing tax, collaborating through the triple-helix model, sharing resources and competences, and creating innovation business communities from the local and the national to the international level. Thus, governmental agencies are recommended to use the RL assessment tool, as part of their execution of supportive programs. The government might assess the readiness levels of several IDE startups.
and then investigate and benchmark the results. The analysis results can be used as references for making decisions on the allocation of resources and provision of support. The government might also share the assessment results with IDE startups and find solutions together to enable IDE startups to achieve sustainable growth or self-reliance with minimal governmental support.

As there are numerous IDE startups, the government might apply the readiness assessment to divide them into clusters, according to the results of their readiness assessment. For example, Gerdsri et al. [33] proposed an approach for clustering business incubators, in the form of a performance–capability matrix. This matrix reports the positions of business incubators, indicating how high/low their performances and capabilities are. This matrix leads to four clusters of business incubators that require four different directions to drive them. Similar to the IDE startups case, the government might develop a matrix to cluster IDE startups, based on their readiness and performance. This clustering facilitates the government’s designing, categorizing, and matching of support to appropriate IDE startups, rather than focusing on their size or geographical location. Moreover, the readiness assessment results can be used to develop the knowledge-based community among IDE startups by focusing on knowledge exchange [34] and the development of knowledge clusters [35]. The IDE startup with the highest level of readiness in each dimension is regarded as a champion in that dimension, so that particular IDE startup can act as a mentor by sharing its knowledge and experiences, related to that dimension, with other IDE startups in the community. The IDE startup champion can actively engage in community development, for example by arranging meetings and seminars to transfer knowledge, establishing a talent mobility program, or collaborating on projects with less capable IDE startups. These approaches have been practiced to develop the sectoral innovation business ecosystem [36,37]. For example, among the three demonstrated cases, Company C performed better in the CRL in 2006 than Companies A and B. According to the concept of knowledge-based community development, Company C should be invited to share its insights into the commerce dimension (e.g., how to apply proprietary technology to develop other products) with others. As a result, Companies A and B would apply the lessons learned from Company C to speed up their development of commerce capability. This would lead to new benefits or opportunities. For example, Company C might obtain new products or new markets from the collaboration, while Company B and Company C might gain more sales in the product life cycle from acceleration.

Thirdly, corporate venture capitalists play vital roles in supporting IDE startups, particularly in financing and marketing. Corporate venture capitalists can apply the readiness assessment results to the three missions of planning supportive strategies, clustering IDE startups, and developing a knowledge-based community. Corporate venture capitalists should use the RL assessment results as references for their decisions on the appropriate allocation (and prioritization) of resources to each IDE startup. In the scenario of multiple IDE startups in a portfolio, corporate venture capitalists should cluster IDE startups to categorize the contributions to each cluster. For example, Manotungvorapun and Gerdsri [38–41] proposed an analytical approach for positioning academic partners to align with the proper modes of university–industry collaboration and presented an understanding of complementary and compatibility dimensions for decisions on partnership management. Similarly, corporate venture capitalists might position IDE startups by incorporating dimensions of complementarity, compatibility, and readiness to design sustainable partnership management programs. For the mission of developing a knowledge-based community, corporate venture capitalists might identify IDE champions from the RL assessment and contribute resources to those champions for the engagement of community or business ecosystem development [42].
8. Conclusions, Limitations, and Future Studies

IDE startups play key roles in national innovation development in the era of the innovation-centered economy. However, IDE startups have varying readiness levels to reach maturity or sustainable growth. They demand support, in particular financing and marketing support, from other players in the business ecosystem. While governmental agencies and large corporate capitalists provide support, some IDE startups can survive and grow in the marketplace but some encounter failure. The effectiveness of support for IDE startups has been considered. A strong business ecosystem, with the existence of self-dependency and sustainable growth among IDE startups, is one of the ambitious goals in countries’ national innovation development policy. Hence, the RL assessment for IDE startups becomes necessary to accomplish the goal of providing effective support. This research addressed the demand for the RL assessment and employed the qualitative methodology to propose the RL framework and develop the RL assessment tool. The RL framework offers academic contributions by connecting readiness levels among the four dimensions of technology, manufacturing, business, and commerce. Meanwhile, the RL assessment tool provides managerial implications for IDE startups, governments, and large corporate venture capitalists. IDE startups can use the results of self-assessment to develop their strategic plans toward maturity. Meanwhile, governmental agencies and large corporate venture capitalists can apply the assessment results to cluster IDE startups, plan their contributions of support, and further develop the business ecosystem.

However, some limitations of this paper should be realized. The scales developed in this assessment tool may have to be adjusted in the future, as many disruptions or uncertainties are likely to arise and the roles of IDE startups, governments, and corporate venture capitalists may have to change over time. Consequently, the validity of the assessment framework might have to be revisited and revised occasionally to adapt to the altering context. To develop the readiness assessment tool further, the accuracy and resolution of the distributive readiness level should be highlighted.

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Appendix A. Examples of Questions to Assess Readiness Levels

| Questions To Assess Technology Readiness Levels (TRLs) |
|------------------------------------------------------|
| Topic 1: the observation of development fundamentals. |
| • Is there a concept and process proposition to support the development foundations? |
| • Do the foundations (physical and chemical) support the concept? |
| • Is there a report of scientific observations? |
| • Is there development (mathematical or scientific) of the concept? |
| Topic 2: the identification of concept applications, |
| • Is there an identification of working policy? |
| • Are there any analysis documents that have been verified by experts? |

| Questions To Assess Manufacturing Readiness Levels (MRLs) |
|---------------------------------------------------------|
| Topic 1: the identification of material qualifications. |
| • Are any developments leveled at TRL 1 or above? |
| • Is there a qualification standard for the materials used? |
Topic 2: the identification of the manufacturing direction.
- Are there any manufacturing concepts and solutions that might newly emerge?
- Is there an identification of cost elements?
- Is there an assessment of raw material accessibility and adequate quality?

Questions To Assess Commercial Readiness Levels (CRLs)
Topic 1: readiness for commercial management.
- Describe how your firm or enterprise designs its commercial management.
- How can you measure products’ and services’ commercial efficiency (e.g., sales, market proportion, profit ratio, etc.)?
Topic 2: directions of product and service development.
- Describe your directions for the future development of products, services, technology push, and marketing motives.

Questions To Assess Business Readiness Levels (BRLs)
Topic 1: readiness for business management.
- Are there at least two vigorous founders who have different skills? (Can you identify different specializations?)
- Can your team identify specific, important, and high-impact problems?
Topic 2: directions for business growth.
- Can your firm set a price and design a business plan, that relates to the industry, to use as evidence for revenue setting?
- Is there primary evidence of similar problems from past experience?
- Does the firm have a business growth vision that can deal with big and global-scale problems in 10 years?

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