NITI Aayog

A NEW LENS FOR INNOVATION IN NEW INDIA

Introducing the Techno-Commercial Readiness and Market Maturity Matrix

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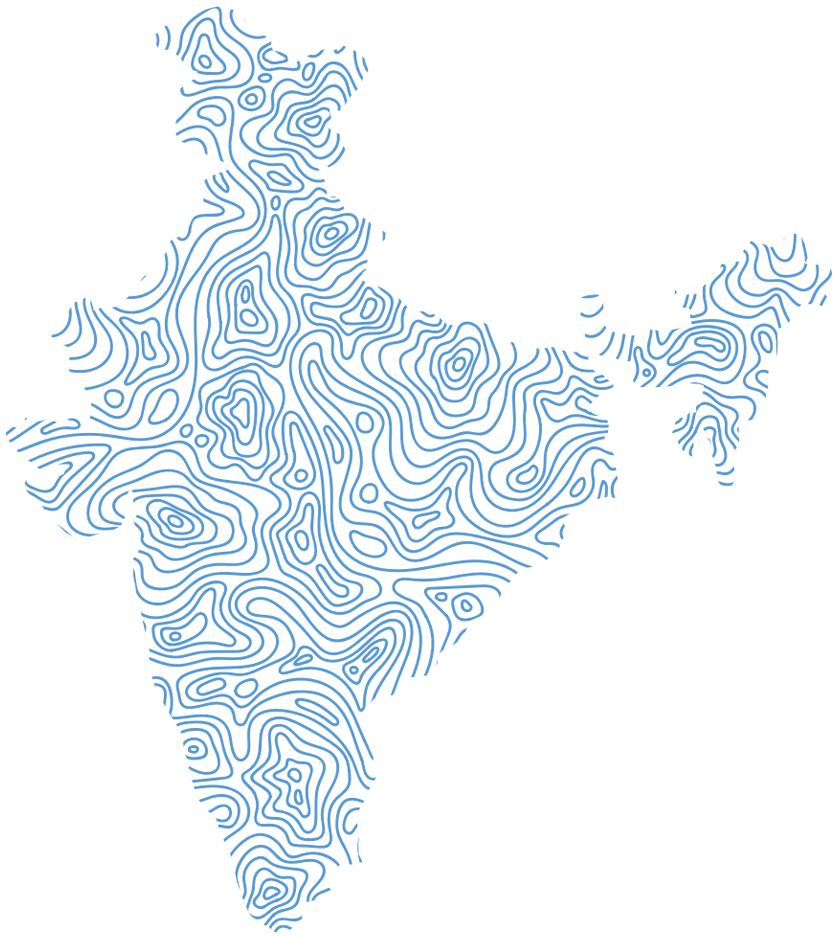

July 2023

A NEW LENS FOR INNOVATION IN NEW INDIA - INTRODUCING THE TECHNO-COMMERCIAL READINESS AND MARKET MATURITY MATRIX

Publishing Agency: NITI Aayog

Year of Publication: 2023

Language: English

ISBN : 978-81-956821-6-4

NITI Aayog
Government of India,
Sansad Marg, New Delhi–110001, India

Authors: Dr. V.K. Saraswat, Dr. Neeraj Sinha, Sh. Naman Agrawal, Ms. Naba Suroor, Sh. Siddhey G Shinde

Report and Cover Design by YAAP

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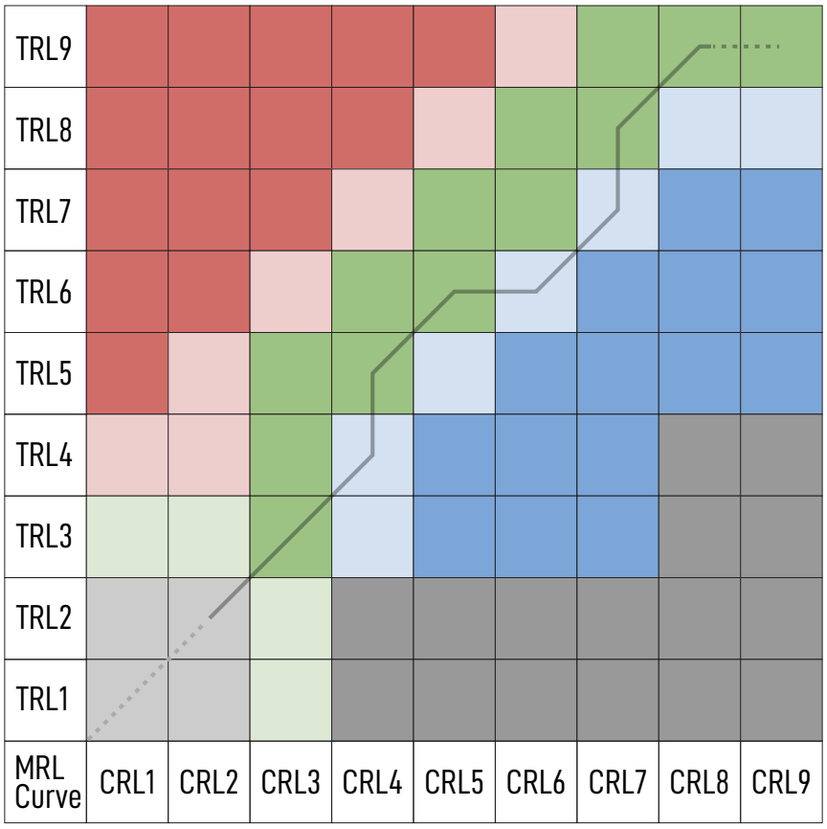
Executive Summary

This paper draws attention to the evolution of the Technology Readiness Level (TRL), Commercialization Readiness Level (CRL), and Market Readiness Level (MRL) scale and their advantages and limitations. It proposes a joint assessment framework, the Techno-Commercial Readiness and Market Maturity Matrix (TCRM Matrix) framework (which can offer additional insights and actionable intelligence.

Table 1: The TCRM Matrix framework and its Legend



LEGEND		Concrete Idea	Commercial Lag (small)	Technological Lag (small)	Diffused Idea
/	MRL Curve	Optimum Path	Commercial Lag (large)	Technological Lag (large)	Not Possible, by definition
The MRL Curve increases by one 'level' every time it moves to the next cell in the matrix					

The paper highlights the different models of innovation that influenced the development of the joint assessment framework and further underlines how it can be utilized and made more acceptable for major funding bodies, countries, and firms for adoption. The basic principles, context, and objectives within which the TRL, CRL, and MRL scales were developed over the years have served as the tools and blueprint for the evolution of the proposed TCRM Matrix framework. At the same time, the framework has been developed

within a mission-oriented programme development approach. It has also illustrated the validation of the framework that can be seen with other project development models as well as understanding different case examples, which serves as a good reference for other organizations and institutions for technology assessment, funding, and interventions at different stages of the technology development cycle. Further, the paper gives a way forward for policymakers, strategists, academicians, and investors on how to integrate the framework within the larger ecosystem of innovation, and entrepreneurship.

The paper elaborates on the key requirements and rationales for adopting the framework and whether it can lead to significant positive implications as well as the constraints, if any, in implementing this framework. It has also been specified that an extensive exercise has to be done before adopting the framework within any specific environment. The framework adoption has to be within the national and sectoral innovation facets.

1. Background – Landscaping the Indian R&D Ecosystem

India's R&D ecosystem is not just about numbers and statistics, but also about the dreams, aspirations, and struggles of millions of people who believe in the power of innovation and creativity. For a country that has faced numerous challenges and obstacles over the years, the growth of the R&D ecosystem is a testament to the resilience, perseverance, and ingenuity of the Indian people. From the remote villages of rural India to the bustling metropolises of the big cities, people are constantly striving to create something new that can change the world.

The government's initiatives to promote R&D and entrepreneurship have given hope to countless individuals who would otherwise have given up on their dreams. The start-up ecosystem has provided young and ambitious entrepreneurs with a platform to turn their ideas into reality. Academic and research institutions have become a breeding ground for innovation and cutting-edge research.

India's R&D ecosystem is more than just a means to an end. It's a way of life. It's about people pouring their hearts and souls into their work, countless sleepless nights pursuing their goals and refusing to give up in the face of adversity. It's about the passion, the drive, and the unrelenting spirit that defines the Indian people.

As India grows and develops, its R&D ecosystem will play a critical role in shaping its future. It will be the engine that drives innovation, the catalyst that spurs growth, and the beacon of hope that inspires future generations. For those who believe in the power of ideas, the magic of creativity, and in the limitless potential of the human spirit, India's R&D ecosystem is a source of inspiration and wonder.

India's R&D ecosystem has been rapidly growing and transforming in recent years, backed by several key facts and figures that demonstrate the country's potential and success:

- The Indian government has launched several initiatives to promote innovation and entrepreneurship, including the Atal Innovation Mission, the National Innovation Foundation, and the Science and Engineering Research Board.
- India has over 1,000 higher education institutions that offer R&D facilities, including the Indian Institutes of Technology, the Indian Institutes of Management, and the Indian Institutes of Science Education and Research.
- Pharmaceuticals, biotechnology, information technology, and automotive industries account for a significant portion of R&D investment in the country.
- India's start-up ecosystem has grown rapidly, with over 50,000 start-ups in the country. This is supported by a strong network of incubators and accelerators, which have helped to nurture and support these innovative companies.
- India has become a significant contributor to global research output, ranking third in the world in the number of research publications. In 2020, Indian researchers published over 135,000 research papers.
- The Indian government has also been promoting international collaborations in R&D, including partnerships with the United States, Japan, Germany, and the United Kingdom.
- The Indian pharmaceutical industry, a significant contributor to the country's R&D ecosystem, has been rapidly expanding. According to the India Brand Equity Foundation, the industry is expected to grow at a compound annual growth rate (CAGR) of 22.4% between 2020 and 2025, reaching a market size of $120-130 billion by 2030.
- India's automotive industry has also been investing heavily in R&D, with several major players, such as Tata Motors, Mahindra & Mahindra, and Bajaj Auto, setting up R&D centres in the country.
- According to the Global Innovation Index 2022, India was ranked 40th in the world in terms of R&D expenditure as a percentage of GDP, with a score of 0.7%. In absolute terms, India's R&D expenditure increased from $23.8 billion in 2010 to $89.9 billion in 2019

These facts and figures paint a picture of a rapidly developing and vibrant R&D ecosystem in India, with enormous potential for growth and innovation. The country's talented workforce, supportive government policies, and strong network of academic and research institutions and private sector partners all contribute to its success.

2. Indian Economy Overview

India's economy has witnessed remarkable growth and is currently leading among the world's major economies. India is anticipated to command one of the top three global economic positions in the forthcoming decade as it draws support from its sound democratic policies and formidable partnerships.

India has surpassed the UK as the fifth largest economy during the initial quarter of FY 2022-23, following its recovery from the tumultuous impact of the covid pandemic surges. Thanks to its robust macroeconomic fundamentals, the Indian economy has demonstrated exceptional endurance, surpassing other growing economies in performance.

India boasts the world's third largest number of unicorns, with a whopping 100 combined valuation of US$ 332.7 billion. The government prioritises using sustainable energy sources and aims to secure 40% of its energy from non-fossil-based sources within the next ten years. The economy of India is majorly influenced by domestic demand, where approximately 70% of the economic activity is driven by consumption and investments. India must continue to prioritise introducing and implementing policies to promote economic growth.

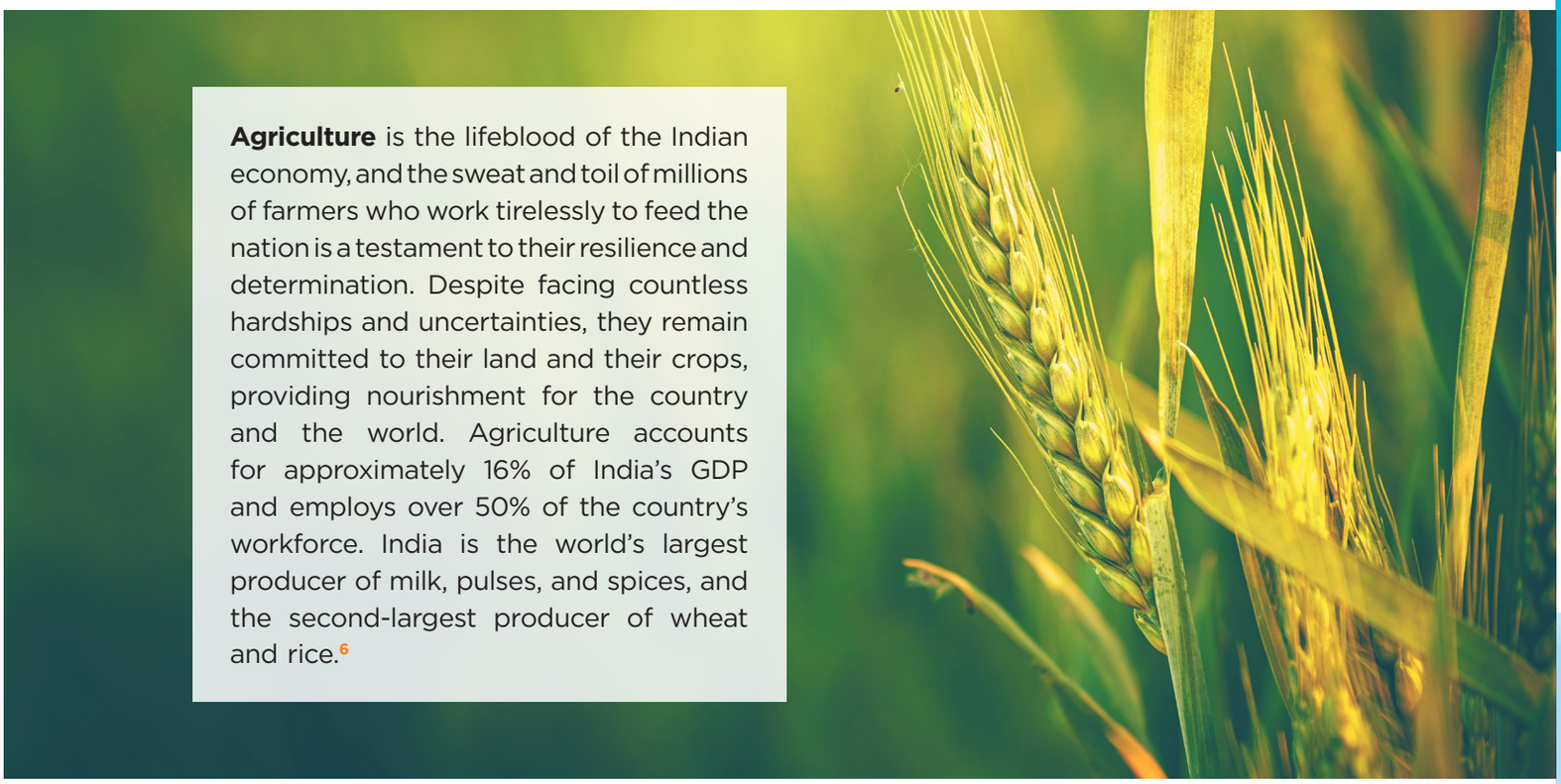
Research and development (R&D) play a vital role in driving economic growth, developing sustainable solutions, improving efficiency, and increasing business competitiveness. The prosperity and development of worldwide businesses and industries depend heavily on this crucial factor. For a nation to develop and maintain its progress, it is essential to convert its science, innovation, and research and development system.

2.1 Sectoral Strength

India's strength lies not only in its diverse economy, but also in the unwavering spirit of its people. The country has overcome numerous challenges throughout its history, from colonialism to poverty and inequality, and yet it continues to stand tall and persevere.

The IT and software industry represents the dreams and aspirations of a generation of young Indians who have worked tirelessly to build world-class companies from scratch. They have created an industry that not only generates wealth for the country, but also inspires the world with its innovative spirit and passion for excellence. The IT and software industry in India is projected to grow at a compound annual growth rate (CAGR) of 14.4% between 2020 and 2025, reaching a market size of USD 194 billion by 2025.[1]

- The IT and software sector contributed USD 191 billion to India's GDP in 2020, accounting for 7.7% of the country's total GDP.[2]
- India is the largest global sourcing destination for the IT industry, accounting for approximately 67% of the market share.[3]
- The sector employs over 4.4 million people in India, with approximately 130,000 new jobs added each year.[4]
- India is home to more than 16,000 IT and software companies, including major multinational corporations such as IBM, Microsoft, and Google.[5]



Agriculture is the lifeblood of the Indian economy, and the sweat and toil of millions of farmers who work tirelessly to feed the nation is a testament to their resilience and determination. Despite facing countless hardships and uncertainties, they remain committed to their land and their crops, providing nourishment for the country and the world. Agriculture accounts for approximately 16% of India's GDP and employs over 50% of the country's workforce. India is the world's largest producer of milk, pulses, and spices, and the second-largest producer of wheat and rice.[6]

- India is the world's second-largest producer of fruits and vegetables, with an estimated annual production of 275 million tonnes.[7]
- The country is also the world's largest producer of spices, with over 63 different varieties produced.[8]
- India is the largest producer and consumer of pulses (edible seeds of legumes), accounting for approximately 25% of global production.[9]
- Agriculture and allied sectors employ over 50% of India's workforce, or approximately 234 million people.[10]

The Pharmaceutical industry represents hope for millions of people who struggle with illness and disease. Indian companies have brought affordable and life-saving medicines to millions of people around the world, demonstrating their compassion and commitment to improving the lives of others. The pharmaceutical industry in India is projected to grow at a CAGR of 11.5% between 2020 and 2025, reaching a market size of USD 65 billion by 2024. India is the largest provider of generic medicines globally and accounts for 20% of global exports in generic drugs.[11]

- The Indian pharmaceutical industry is the world's third-largest by volume, with over 20,000 registered companies.[12]
- India is the world's largest provider of generic medicines, accounting for 20% of global exports in generic drugs.[13]
- The sector is projected to reach a market size of USD 130 billion by 2030, growing at a CAGR of 15.92% between 2021 and 2030.[14]
- India is also a major supplier of vaccines to the world, with over 60% of the world's vaccines produced in the country.[15]

The Automotive industry represents the ingenuity and creativity of Indian entrepreneurs who have built thriving businesses from nothing. Their hard work and determination have created jobs and opportunities for countless people, fueling the country's economic growth and development. The automotive industry in India is expected to become the world's third-largest by 2025, with annual sales of over 13 million vehicles. India is also the world's largest manufacturer of two-wheelers, with over 21 million produced annually.[16]

- India is the world's largest manufacturer of two-wheelers, with over 21 million produced annually.[17]
- The sector contributes approximately 7.1% to India's GDP and employs over 35 million people.[18]
- India is also a major hub for the production of electric vehicles, with the government targeting a goal of 30% electric vehicle adoption by 2030.[19]

Further, **the Textile industry** in India is the second-largest employer after agriculture, providing jobs to over 45 million people. India is the world's largest producer of cotton and jute, and the second-largest producer of silk. The industry is expected to grow at a CAGR of 10% between 2020 and 2025, reaching a market size of The Indian automotive industry is the world's fourth-largest by volume, with over 26 million vehicles produced in 2019.[20]

- India is the world's second-largest producer of textiles and garments, accounting for approximately 5% of global exports in textiles.[21]
- The sector employs over 45 million people, making it the country's largest employer after agriculture.[22]
- India is the world's largest producer of cotton and jute, and the second-largest producer of silk.[23]
- The sector is expected to grow at a CAGR of 13.6% between 2021 and 2026, reaching a market size of USD 350 billion by 2025.[24]

Finally, India's focus on **Renewable energy** is a reflection of the country's commitment to creating a better future for its people and the planet. It represents a bold vision of a sustainable and equitable world, where people and the environment can thrive together. India's renewable energy capacity has grown at a CAGR of 17.33% between 2014 and 2020, reaching a total capacity of 92.97 GW in 2020. India has set a target of achieving 175 GW of renewable energy capacity by 2022, including 100 GW of solar power. India is ranked fourth globally in terms of installed renewable energy capacity, after China, the US, and Brazil.[25]

These figures demonstrate the significant potential for growth and development in India's sectors, and highlight the important role they play in the country's economy and society. In conclusion, India's strength is not just in its economy, but in the passion and determination of its people. They are the heart and soul of the country, driving it forward with their unwavering spirit and unbreakable will.

India has recorded impressive progress in recent years in extending access to **Financial Inclusion and Services** to a larger portion of the population, including disadvantaged socio-economic groups. Leveraging the country's competitive strength in ICT, the Unified Payments Interface (UPI) and other tools are easing the transition towards a cashless economy.

The India Post Payments Bank (IPPB) is set up under the Department of Post, Ministry of Communication, and has expanded its strength across India covering post offices, through a network of one Branch and 649 Banking outlets manned by Business Correspondents, working on a hub and spoke model.

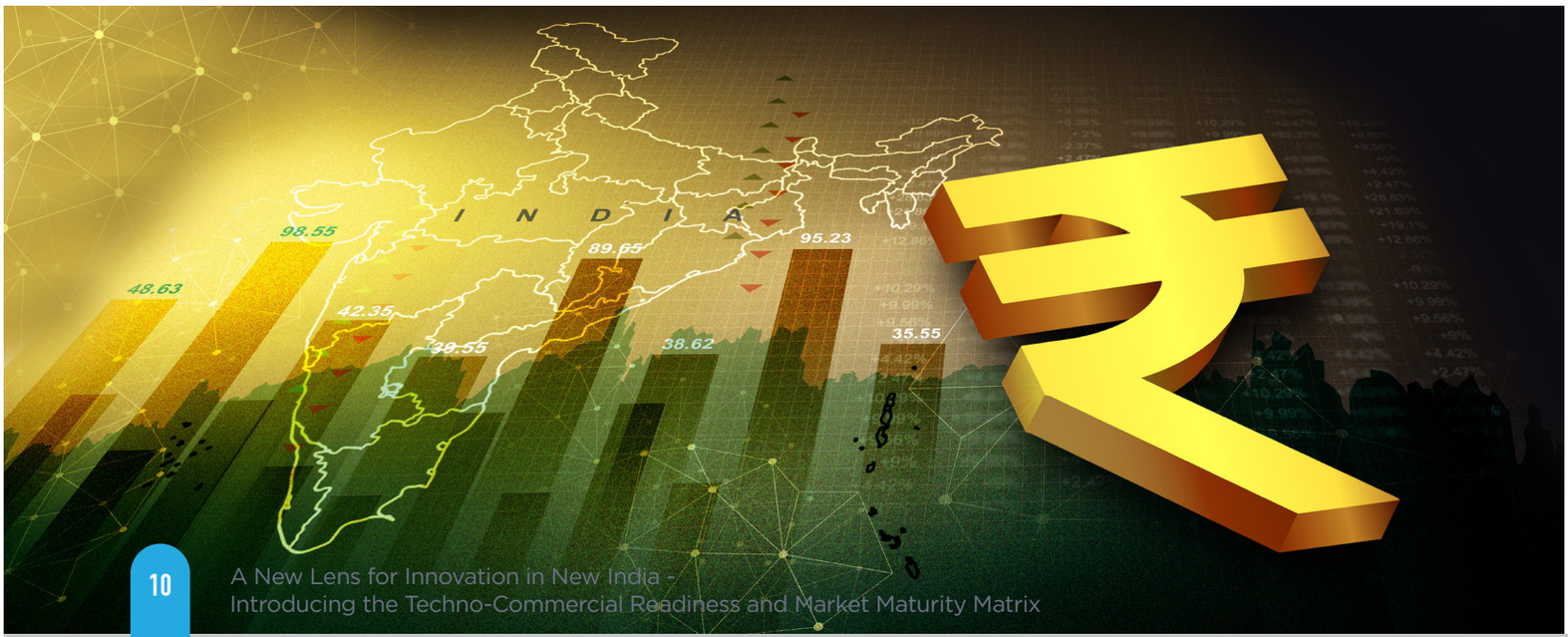
India Post Payments Bank (IPPB) enabled >1.36 lakh post offices to provide banking services, including access to every Aadhaar-linked bank account, at the customer's doorstep, resulting in ~2.5x increase in rural banking infrastructure, and ~572,551 villages were provided with mobile and internet connectivity. With over 400 banks live on the Unified Payment Interface (UPI) platform, the transaction volume achieved an all-time high in April 2023 at over 8.8 billion transactions. Further, the recently launched UPI123Pay for feature phones will allow payments over apps, missed calls, interactive voice response, and even using proximity sound. The government uses JAM's (Jan Dhan-Aadhaar-Mobile) direct benefit transfers for ~317 services. In FY21, it conducted 2.6 billion transactions, transferring >US$ 46 billion to beneficiaries.

2.2 Startup and Investment Boom

India has been witnessing a boom in startup activity and investment in recent years, with a particular focus on research and development (R&D) in a wide range of sectors. The Indian government has implemented several initiatives to promote innovation and entrepreneurship, including the Startup India campaign and the Atal Innovation Mission, which provide support and funding to early-stage startups.

According to a report by NASSCOM and Zinnov, India added over 1,600 new tech startups in 2020, taking the total number of startups in the country to nearly 12,000. In 2020, Indian startups raised over $10 billion in funding, despite the challenges posed by the COVID-19 pandemic. This is a 10% increase from the previous year. India has the third-largest startup ecosystem in the world, after the United States and China.

The Indian government's Startup India initiative has supported over 41,000 startups since its launch in 2016, and has approved over 700 funds for investment in startups. India is home to several unicorns (startups valued at over $1 billion), including Flipkart, Paytm, Ola, and



Byju's. The Indian government has set a target of increasing the country's R&D spending to 2% of GDP, up from the current level of around 0.7%.

The number of patents filed by Indian companies and individuals has been steadily increasing in recent years. According to the World Intellectual Property Organization (WIPO), India filed over 53,000 patent applications in 2019, up from around 47,000 in 2018. These facts and figures highlight the significant growth and potential of the Indian startup and R&D landscape. The government's initiatives and policies, combined with the increasing investment and entrepreneurial spirit of Indian innovators, are driving the country's emergence as a leading hub for innovation and research.

The focus on R&D has also attracted significant investment from domestic and international investors, with companies such as Reliance Industries, Tata Group, and Infosys investing heavily in research and development activities. In addition, several venture capital firms and angel investors are also pouring funds into promising startups with innovative ideas. The startup boom is not limited to just one sector, with startups emerging in areas such as fintech, edtech, healthtech, agritech, and e-commerce, among others. This diverse range of startups is contributing to the growth and development of the Indian economy, and creating job opportunities for thousands of people.

The Indian government has also introduced several policies to boost the country's R&D capabilities, including tax incentives for companies engaged in R&D activities, and the establishment of several innovation and research parks across the country. Overall, the startup and investment boom in India's R&D landscape is a positive sign for the country's economic growth and development. The focus on innovation and entrepreneurship is driving the country's transformation into a knowledge-based economy, and positioning India as a global hub for innovation and research.

3. Need for Assessing Tech-based Projects

Technology assessment entails conducting a scientific investigation into the potential implications of technological advancements and providing civil society and political actors with advice based on the results. It is an interdisciplinary activity that seeks to determine potential consequences on many facets of life as a response to new scientific and technical breakthroughs, artifacts, processes, services, societal concerns, and concrete policies. Technology Assessment has always had the responsibility of assisting the national policymaking community in the creation of an effective Science, Technology, and Innovation (STI) policy.

One must carefully evaluate the difficulties involved in attempting to apply technology assessment techniques in the context and realities of a developing nation like India. The evaluation must take into account the local context, and function according to local needs and capabilities.

India has become a centre for technological innovation on a worldwide scale, with a rapidly growing tech industry. As a result, there are now more startups and technology-based enterprises nationwide. But not all of these initiatives are successful, and some don't produce the desired results. Therefore, it is critical to evaluate these projects' viability and potential before investing and devoting time and resources to them. In India, technology has the power to drastically transform a number of industries, including healthcare, education, agriculture, and transportation. The entire quality of life for individuals in the nation can improve by evaluating and monitoring the tech-based initiatives in various industries to help identify gaps and potential for innovation.

3.1 Status of Tech Development

Assessing technological initiatives can assist in offering a comprehensive view of the country's technological development status. We can discover areas of strength and possibilities for development in the country's tech ecosystem by examining the performance and effect of these projects. Successful technology-based initiatives, for example, can highlight the country's strength in sectors such as digital infrastructure, technological innovation in healthcare solutions, and so on. This might be a sign of a skilled workforce, helpful government policies, and a favorable investment climate.

Failure of technology-based initiatives, on the other hand, might identify areas that require development. It might imply a lack of money, insufficient innovative support, regulatory obstacles, or talent shortfalls. Addressing these difficulties may aid in the creation of a more favorable environment.

Assessing tech-based projects can also help to identify emerging trends and opportunities. For instance, if we see a significant number of successful projects in a particular sector such as healthcare, it could be an indication of the potential for growth and innovation in that sector.

Over the last few decades, India has made significant progress in the field of technological development. The country currently has a thriving technology industry, with a slew of startups, global IT behemoths, and innovation hotspots. Here are some of the key highlights of India's technological development status:

- **Startup Ecosystem:** India has emerged as the third-largest startup ecosystem in the world. These startups are driving innovation across various sectors, including healthcare, finance, education, and transportation.
- **Digital Infrastructure:** India is investing heavily in its digital infrastructure, with the government's Digital India initiative driving the country's digital transformation. This has led to a proliferation of smartphones, internet connectivity, and digital payment systems.
- **Artificial Intelligence (AI) and Data Analytics:** India is emerging as a hub for AI and data analytics, with a growing number of startups offering AI-based solutions and services.
- **Healthcare:** India has a rapidly growing healthcare sector and technology adoption plays a key role in improving healthcare outcomes. The country is home to a number of health tech start-ups offering solutions such as telemedicine, digital health records, and health monitoring devices.
- **Agriculture:** India's agriculture sector is also undergoing a technology-driven transformation, with start-ups offering solutions such as precision agriculture, soil testing, and crop monitoring.
- **Digital Payments:** India, primarily a cash-based economy, now leads the world in real-time digital payments. Now, a global leader in the fintech space, India has announced the systematic introduction of the digital rupee by the central bank at the Union Budget 2022-2023.

3.2 Determination of Future Funding

Future funding for startup or technical projects is determined by a number of elements, including the stage of development of the startup or project, its industry, its business model, and its potential for growth. Some of the main elements that investors frequently take into account when choosing a funding source:

- **Emerging Technology:** Any innovation or a startup is more likely to be adopted/ receive funding if they are using any futuristic and emerging technology to solve issues or open up new opportunities. Investors seek out startups with cutting-edge, proprietary technology that gives them a competitive edge.
- **Market size and potential for growth:** Investors frequently seek out technologies / innovations / startups that are aiming to capture sizable and expanding markets. Startups are more likely to receive funding if they are addressing a significant issue or opportunity and have the potential to grow quickly.
- **Business Model:** Investors are more attracted to companies with a distinct and scalable business model. Long-term success depends on a business model that can produce stable revenue streams and profits.
- **Market Traction:** Startups are more likely to be supported if they have already shown some degree of market traction, such as revenue growth or user acquisition.

3.3 Valuation and Investment

Valuation and investment refer to the exercise of assessing the potential value and financial viability of a new technology or innovation or project and making investment decisions based on that assessment.

Valuation is the process of defining the potential worth of an innovation or technology by evaluating various factors such as market potential, competitive landscape, and intellectual property. This assessment helps investors to determine the value of the startup and make investment decisions based on that valuation.

Investment, on the other hand, refers to the process of providing financial resources such as equity or debt funding to a startup or project to help it grow and achieve its objectives. Investors typically make investment decisions based on the valuation of the startup and its potential for success.

In summary, valuation and investment in a new technology involve assessing the potential value and financial viability of a startup or project and making investment decisions based on that assessment.

3.4 Technology Transfer in India

The exchange of knowledge or information about technological aspects within a group or between organisations or institutions is known as technology transfer or technology commercialisation.

Internationally speaking, this is referred to as the transfer of technology, encompassing the exchange of expertise, production methods, tangible resources, specialised expertise, and other technical factors between countries. The efficient application of the received technology and its eventual integration furthers the progress of technology and fosters innovation.

The technology transfer process involves the transfer of technology from the laboratory to the industry or from one application to a different domain application. Technology transfer in developing countries facilitates the acquisition and dissemination of advanced technologies from developed countries, thus enabling the transition towards newer technological advances.

India has chosen to use an intelligent combination of domestically produced and imported technology, contributing significantly to the country's overall development and economic prosperity. "Technology transfer" is crucial and is typically covered by a technology transfer agreement. In contrast with conventional development approaches, emerging economies like India frequently utilise their expertise in advanced technology to embrace and execute contemporary techniques for progress.

The Indian government has built numerous national research laboratories in order to conduct research and development, with the intention of sharing the resulting technological advancements with developing and underdeveloped countries. The Indian government has also established Technology Transfer Offices at the Central Government level and in universities and institutions, supported by central funding, that serve as a means of disseminating and exporting the results of research to the intended destinations.

Several Indian Academic Institutes are also successfully commercialising their research and transferring their technology to industry through licensing. Furthermore, several reputable institutions have witnessed multiple instances of technology dissemination in India.

The coronavirus outbreak sparked a greater curiosity in comprehending the significance of transferring technology internationally in order to enhance the worldwide manufacture of vaccines. Amidst the covid outbreak, nations with prior exposure to vaccine production via the technology transfer program displayed superior readiness in formulating a remedy for combatting the pandemic. With the technology transfer of vaccines, India has emerged as a leading global centre for manufacturing covid vaccines, constituting almost 60% of the world's vaccine supply capacity.

3.5 Technology Commercialization

Following independence, the Government of India (GoI) established a number of organizations and institutions to handle the transmission of knowledge and inventions across the country. The Government of India founded the National Research Development Corporation (NRDC) in 1953 with the primary goal of promoting, developing, and commercializing technologies / know-how / inventions / patents / processes emerging from various national R&D institutions / universities. It is currently managed by the Department of Scientific and Industrial Research, Ministry of Science and Technology, Government of India. Following that, the first scientific policy, enacted in 1958, highlighted the importance of technology in India. Among a few research and development enterprises, India has a track record of achievement. One such project comes from the National Chemical Laboratory (NCL), a principal laboratory of The Council of Scientific and Industrial Research (CSIR) of India's central government. NCL has an exceptional history of commercializing technologies both in India and overseas in conjunction with industry over its 80-year history. The Technology Information Forecasting and Assessment Council (TIFAC)[26] was established in 1988 as an autonomous body owned by the Government of India under the Department of Science and Technology to provide financial support for infrastructure as well as to develop and commercialize technologies under the "Home Grown Technology" Scheme.

To emphasize the importance of promoting local goods, the Government of India announced the "Make in India" initiative in 2014, which comprises key characteristics to encourage inventions, protect intellectual property, foster innovation, and construct the best manufacturing infrastructure in the country. The first National Intellectual Property Rights (IPR) policy was announced in May 2016. The GoI's goal with this policy was to promote, raise awareness of, and enforce intellectual property.

In India, research institutes have strong research competencies in a wide range of fields, many of which have significant commercial potential. However, considerable work needs to be done before they can be translated into commercial products and services. First, a market need (or problem) must be discovered, followed by a "proof-of-concept" project in which a technical solution is produced and tested. Furthermore, more research is needed to determine whether this technological solution can be offered in a cost-effective and commercially sustainable manner. There is a significant shortage of professionals to support the technological commercialization process. Professionals such as IP lawyers, legal service providers in technology transfer, business plan writers, counsellors in company formation, and other allied services are in high demand. Strong networks must also be developed and cultivated between and among entrepreneurs, technicians, investors, researchers, tech transfer experts, and others. Technology business incubators, which promote tech companies by providing physical space, facilitating finance, and providing other advisory and professional services, are another important component of the ecosystem that must be established and expanded.

4. Overview of Assessment Frameworks

The diverse needs for assessing technology development projects have given rise to various tools and frameworks for conducting such assessments, with each delivering insights tailored to the specific need. These tools utilise both intrinsic and extrinsic indicators for the assessment, and usually compare the project to a standardised benchmark to determine the work done so far and the work that remains to be done. The standardised benchmark is the result of previous experience across the scientific, industrial, and research community in technology development projects. The assessment frameworks can be broadly classified based on which aspect of the project they focus on - namely; technology focused, business focused, and market focused. A few important frameworks from each category are discussed briefly below.

4.1 Technology-focused Frameworks

The most popular among these frameworks is the Technology Readiness Level (TRL) framework, which was originally developed by NASA based on the innovation life cycle. It has since been widely adopted in a more generalised form, and has also become part of the EU Horizon 2020 Work Programme to support Research, Development and Innovation investments. Its popularity as an assessment framework can be attributed to its ease-of-use and intuitive linear progression model from an initial stage of curiosity-driven research to a final stage of fully developed and tested innovation, launched as a new product and/or service. The high level of abstraction allows it to be applied to any kind of technology to produce meaningful insights. However, the TRL framework has also been criticsed because it does not incorporate the cyclical and iterative nature of technology development, and cannot provide meaningful insights when there are disruptive breaks in technological evolution.

An important framework that overcomes these challenges in technological assessments is the 'S-Curve' framework. This framework was developed from the study of innovation from an economic perspective, and looks at the increase in performance of a technology over time. It finds that from the point of introduction of the technology by an innovator, the improvement in performance of a technology usually starts very slowly with early adopters. It then reaches its first inflection point where the performance ramps up quickly with an increase in adoption, and gives a large boost to the intended productivity, before it reaches its second inflection point where it becomes saturated and the performance/ adoption starts to plateau. When such improvement in performance is plotted over time, it looks like a forward leaning 'S', and hence its name. (See figure below). However, this framework also presents a second insight - that there are multiple S curves for the same technology application, and society 'rides' one S-curve to another.

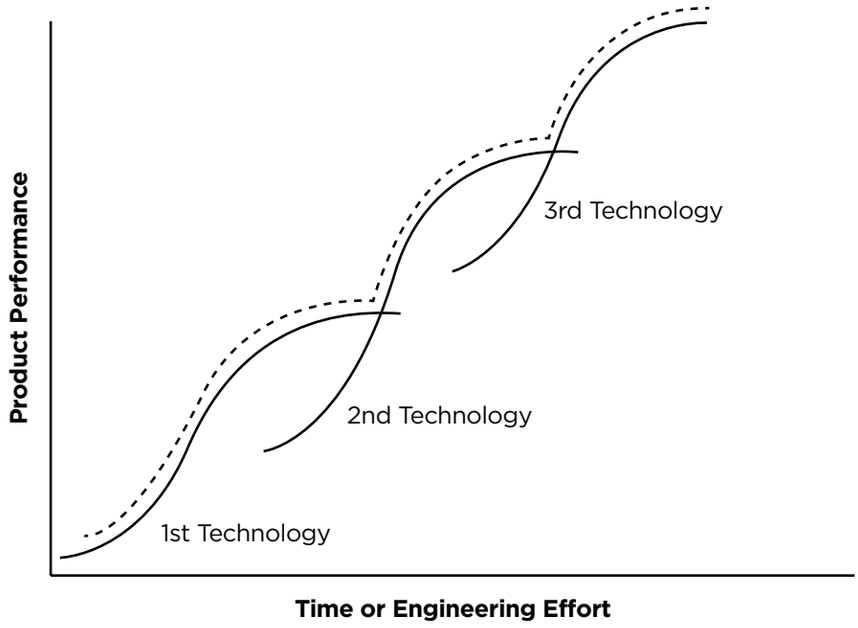


Figure 1: *The S-Curve of Technology Development*[27]

Another useful framework for the assessment of technology development is the 'Dimensions of Technology Development' of a given technology thread. A technology 'thread' is defined as a class of technological solutions and the generational evolution of that technology class. Note that technology threads do not include 'higher' technology that is constructed using the given class as a component. At any given point along the technology thread, there are three dimensions of development. The Production Dimension is a measure of the capability of producing the technology at a large scale (more units of technology). The Performance Dimension is a measure of the capability of improving the technology's performance (more performance per unit of technology). The Progress Dimension is a measure of the capability of innovation towards the evolution of the technology (next generation of technology). While this framework may appear to be similar to the S-Curve, its value lies in its ability to separately identify the direction of technological development.

4.2 Business-focused Frameworks

An important business focused framework is the Commercialization Readiness Level (CRL) framework, which provides a linear progression model from the belief a new technology could be commercially successful all the way through to commercial availability and wider acceptance within the target market. While there are many versions of this framework (including the Investment Readiness Level framework) set out by various government agencies and industry associations, but it has not found the same kind of popularity and acceptance as the TRL framework. This lack of adoption has been attributed to the use of a linear model where the perception of business is non-linear, and the availability of other business focused frameworks that have a similar ease of use while offering more meaningful insights.

One of the most popular business focused frameworks is the Business Model Canvas, developed by Alexander Osterwalder. It provides the logic of how a company intends to

deliver value and make money through nine building blocks that cover the three main areas of a business: desirability, viability and feasibility. This framework offers its ease of use with a high level of abstraction that allows it to be applied to a wide range of business cases, but it does not provide insight into the business challenges along the way of establishing a business.

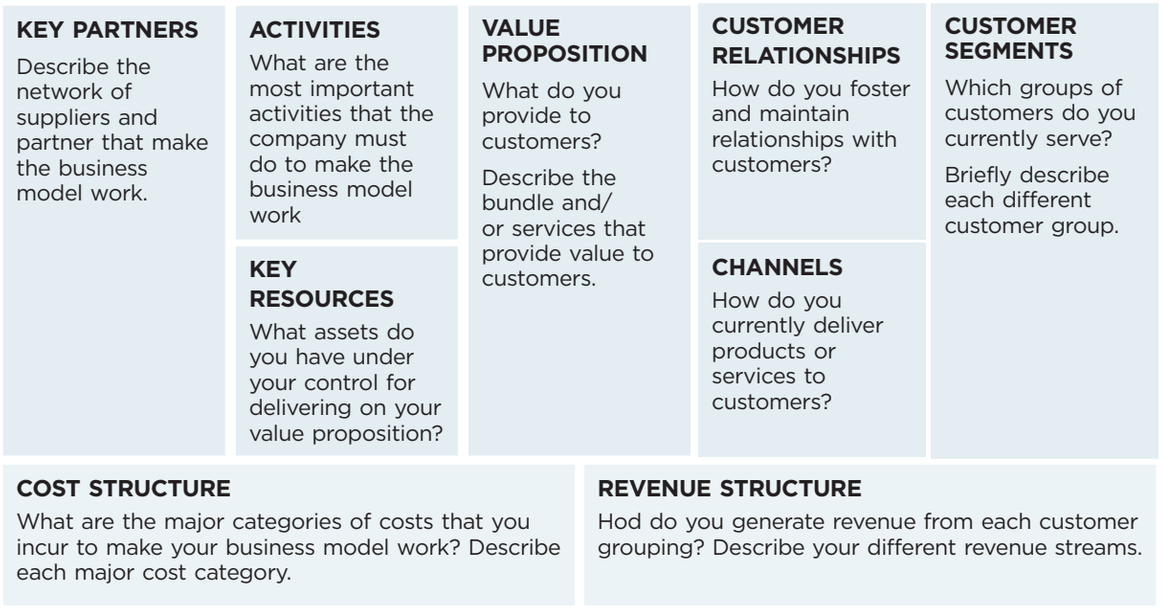


Figure 2: *The Business Model Canvas*[28]

The 'Valley of Death' framework looks at the business life cycle to examine the various points along which significant challenges for the business emerge. Like other frameworks, there are various versions of this framework used across the industry, but a common feature across each 'valley' is that it is defined in a space between the peak attention or support of different stakeholders. For example, the Product Development valley of death lies in the space between public or academic funded research and early stage investor funded startups, while the Scale to Market valley of death lies between the growth stage investor funded startup and publicly listed companies. This framework is very useful in identifying what key stakeholders need to be sensitized and persuaded.

4.3 Market-focused Frameworks

Similar to the other two categories, an important framework here is the Market Readiness Level (MRL) framework. An important distinction here, however, is that it relies on extrinsic indicators - or more specifically, the awareness of extrinsic market indicators - and the preparedness (in the technology development project) for facing the extrinsic scenario in the market. Various versions and forms of the MRL framework have been introduced by government agencies and the industry. While this framework has certainly found higher adoption thant the CRL framework, it is not as widespread in the acceptance as the TRL framework.

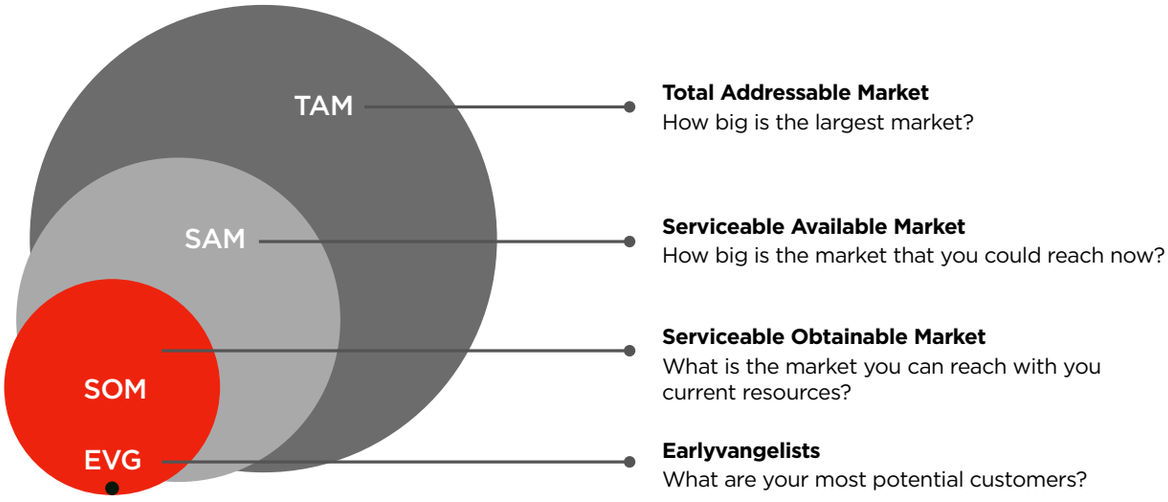


Figure 3: *Market Sizing Techniques*[29]

The most popular method of market focused frameworks rely on market sizing techniques, which is a method of evaluating and estimating the potential reach and revenue of a given product or service. This method relies on overall market size estimates from market surveys and research reports, and then identifies the specific market by applying a series of weights based on various assumptions.

An important feature of the 'Valley of Death' framework discussed in the previous subsection is that it is often also used as a market focused framework. This is possible because the framework relies on extrinsic indicators like the interest and support of various stakeholders to identify the 'valleys'. As a result, the framework is able to provide a close estimate of the market factors affecting the technology development project.

5. Proposed Model for the joint assessment of Technical and Commercial Readiness and Market Maturity

A significant majority of the assessment frameworks usually examine only one aspect of the technology development project, and hence provide an incomplete or lopsided insight in its stage of development. Keeping in mind the hazards of such incomplete assessment that have been covered in detail during the discussion on India's present status and the needs for assessment, the paper here proposes a model for a joint assessment of the technical and commercial readiness and market maturity of a technology development project.

At this point it is highlighted that the idea of a joint assessment framework is hardly new. The challenges and limitations of the individual frameworks were clearly outlined over the 1990s and early 2000s, and several attempts have been made since then to provide a joint technical and commercial readiness assessment framework. Two such efforts worth noting are explained in brief along with our observations.

- The Market & Technology Readiness Level or MTRL[30], developed by Frank Khan Sullivan, Michel Drescher from Oxford University e-Research Centre and Frank Bennett at Cloud Industry Forum, and was originally used to support several European Research & Innovation projects. This framework provides a detailed questionnaire regarding the technological and market readiness, and uses mathematical modeling to create a composite readiness level. We observe that this framework provides a robust analysis of the joint readiness of a project but is not intuitive, reducing its ease-of-use.
- The 4-axis framework[31] extends the Technology Readiness Level in three further directions, namely the Legal, Organisational and Societal Readiness Levels. This framework was developed by Ilenia Bruno and Francesco Molinari, and published in In Proceedings of the 13th International Conference on Theory and Practice of Electronic Governance (ICEGOV2020). We observe that while this framework provides an intuitive extension of the TRL framework in three new directions, it does not add value in terms of joint assessment of the readiness of technology development projects.

The present proposal seeks to present a joint assessment framework that also incorporates the market readiness aspect, and through that, to introduce the notion of an 'optimal path' for such technology development projects. Towards this, we begin by using three linear progression models of assessment frameworks - namely the Technology Readiness Level (TRL), Commercialisation Readiness Level (CRL), and Market Readiness Level (MRL) - as the base versions. These frameworks and their limitations are discussed in detail below.

5.1 Technology Readiness Levels (TRL) Overview and Rationale

TRL is a framework for estimating the technology maturity of core technologies in a program during the selection process and in subsequent monitoring and evaluation phases until these technologies, or products utilizing them, attain market readiness. Originally introduced by NASA (National Aeronautics and Space Administration), the TRL scale is a metric with nine technology readiness levels for describing the maturity of a technology from ideation stage (TRL-1) to highest degree of application in its operational environment (TRL-9).

It is based on the assumption that as a technology advances from basic concept to final implementation, its maturity level increases. The scale is intended to give a standard language for innovators, researchers, and investors to communicate about the readiness of a technology for commercialization or deployment.

Table 2: Technology Readiness Levels (TRL) Scale

Technology Readiness Level (TRL[32])	Requisite Conditions
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and Experimental Critical Function and/or Characteristic Proof-of-Concept
TRL 4	Technology Component / sub-system validation in laboratory environment
TRL 5	Technology Component / sub-system validation in relevant environment (industrially relevant environment in case of key enabling technologies)
TRL 6	Technology sub-system or prototype demonstration in a relevant environment
TRL 7	Technology System Prototype demonstration in an operational environment
TRL 8	Actual Technology System completed and qualified through testing and demonstration
TRL 9	Actual Technology System proven in its operational environment (competitive manufacturing in the case of key enabling technologies)

The TRL was designed to give a framework for assessing a technology's readiness and communicate more effectively about the risks and opportunities associated with a given technology by utilizing a standard language to express the maturity of a technology. This can serve to minimize ambiguity and boost confidence in a technology's potential success, ultimately leading to more informed investment and deployment decisions.

5.2 Commercialisation Readiness Levels (CRL) Overview and Rationale

The CRL will assess various indicators which influence the commercial and market conditions beyond the technology maturity. This enables key barriers to be addressed to support the commercialisation of a technology. It is intended to supplement the TRL scale by providing increased focus on a technology's preparedness for market launch and commercial success through specific and clearly defined business indicators.

Like the TRLs, the CRLs are on a scale from 1 – 9 to identify the commercial readiness of the technology, from basic value proposition stage (CRL-1) to trusted solution (CRL-9). The CRL approach was designed to give a framework for assessing a technology's commercial readiness, primarily for the goal of bringing it to market. This encompasses market analysis, cost-effectiveness, scalability, and regulatory compliance, which are often not addressed by the TRL system.

Commercialisation Readiness Level (CRL[33])	Requisite Conditions
CRL 1	Basic value proposition of technology identified and reported
CRL 2	Business concept formulated with potential applications
CRL 3	Business Plans validated with Proof-of-Business-Case
CRL 4	Minimum Viable Product Completed and Pilots initiated
CRL 5	Minimum Marketable Product and Operational Processes Validated
CRL 6	Minimum Marketable Product Deployed in the Market with Operating Revenue Targets
CRL 7	Matured Product Design and Marketing Strategy Validated
CRL 8	Matured Product Deployed in the Market with Targets Achieved
CRL 9	A Trusted Solution and a successful business model established

5.3 Market Readiness Levels (MRL) Overview and Rationale

MRL is a methodology used to evaluate how close to the market the project outputs / products are. It is used to assess how ready your product or service is to take to market as a commercial offering for a group of customers. The MRL scale is intended to supplement the TRL and CRL by focusing on a technology's preparedness for the purpose of customer adoption and market success.

MRL reflects the evolution of a project from initial project development to market leadership. The level sequence must take into consideration the changes that must occur for a project to transform itself from a purely technology endeavor to a market powerhouse. It aids in accelerating the commercialization of technology and ensuring its success, which will promote innovation and economic progress.

Table 3: Market Readiness Levels (MRL) Scale

Market Readiness Level (MRL)	Requisite Conditions
MRL 1	Basic Market Need Perceived and Defined
MRL 2	Potential Business Models Formulated with Value Proposition
MRL 3	Early Stakeholders Identified and their Needs Validated
MRL 4	Feedback from Pilot of Minimum Viable Product Obtained
MRL 5	Market Sizing for Minimum Marketable Product Completed and Operating Revenue Targets Generated
MRL 6	Problem Solution Fit Validated with Proven Traction and Competitor Analysis Completed
MRL 7	Feedback from Minimum Marketable Product Obtained and Market Research for Matured Product Completed
MRL 8	Product Market Fit Validated with Proven Scalability and Market Share Target Fixed
MRL 9	Continuous Iteration of Product Development through Feedback and Market Research

5.4 Identifying the gaps

Each of the Technology readiness level (TRL), Commercialization readiness level (CRL), and Market readiness level (MRL) systems, have certain limitations which are:

Table 4: Identifying the gaps

Technology Readiness Level (TRL)	Commercialization Readiness Level (CRL)	Market Readiness Level (MRL)
TRLs only take into account a technology's technical readiness, ignoring other elements like market demand, cost-effectiveness, and regulatory compliance that are crucial for commercial success. TRLs do not specify how to advance a technology from one level to the next, making it difficult to design and implement technological development and commercialization strategies.	CRLs are concerned with commercialization readiness and may overlook technical elements of a technology. External variables, such as changes in rules or market conditions, might have an impact on a technology's commercial readiness.	The MRL system may be subjective, and various stakeholders may perceive it differently, resulting in contradictions in ratings. MRLs may fail to account for external factors that can influence technology adoption, such as changes in customer tastes, competition, or technological improvements.

While each approach has certain limitations, they all provide a useful framework for assessing the readiness of a technology from different perspectives. By combining these many viewpoints, stakeholders can make more informed decisions regarding a technology's potential commercial success and establish successful strategies for technological advancement and user adoption.

6. Construction of the Techno-Commercial Readiness and Market Maturity Matrix (TCRM Matrix) Framework

In order to construct a joint assessment framework, we envision a model that will have a high level of abstraction, so that it may be applied to a wide range of technology development projects, and will encourage ease-of-use, so that a user would be able to intuitively utilize it without prior knowledge. Further, we also seek to introduce the notion of an 'optimal' path, but do so with caution to ensure it does not compromise the level of abstraction. Keeping in mind the above, we find that the TRL, CRL, and MRL frameworks, despite their limitations as linear progression models, serve as the best building blocks for the joint assessment framework.

We note that the TRL and CRL framework are distinct from the MRL framework in that the former are based on intrinsic indicators whereas the latter is based on extrinsic indicators. We find that this presents a unique opportunity to improve the ease of use, and leverage this feature in our construction of the Techno-Commercial Readiness and Market Maturity Matrix (or TCRM Matrix).

We also consider two test cases (given below) at each stage to show how the framework being constructed can be used for assessment, and to determine whether it offers any additional insights as compared to discrete assessment using different frameworks.

- The assessment of project (P1) at different points in time (t1, t2, and t3) shows where the focus has been over those time intervals.
- The comparative assessment of various technology Projects (P1, P2, P3) at a given time (t2) shows which are more technically or commercially mature.

6.1 First Stage of Construction

We begin the first stage construction of the TCRM Matrix by taking the two frameworks based on intrinsic indicators - the TRL and CRL framework - and construct a simple but inverted matrix from them as shown in the table below. This table can be used as a rudimentary tool to jointly assess the technical and commercial development stage of any given technology project (or multiple projects).

Table 5: First stage construction of the TCRM Matrix framework, with two test cases

TRL9									
TRL8									
TRL7							P1(t3)		
TRL6			P1(t2)						
TRL5				P2(t2)					
TRL4							P3(t2)		
TRL3	P1(t1)								
TRL2									
TRL1									
	CRL1	CRL2	CRL3	CRL4	CRL5	CRL6	CRL7	CRL8	CRL9

We examine the two test cases using this stage of the TCRM Matrix framework, and find that:

- The project P1 focused more on technological development between t1 and t2, and then shifted focus to commercial development between t2 and t3.
- At time t2, P1 has highest technological readiness, P3 has most commercial readiness, and P2 lies somewhere in between.

We note that at this stage the TCRM Matrix framework does not offer any additional insights needed for the joint assessment to be more meaningful than a discrete assessment.

6.2 Second Stage of Construction

In the second stage of construction of the TCRM Matrix framework we attempt to incorporate the underlying context of the two readiness level frameworks and to link them to each other. This is done by using a colour-coding the matrix to showcase the relationship and interdependence of the TRL and CRL. Through this, we also begin introducing the notion of an 'optimum path'. The path is called 'optimum' because it relies on a given technology project meeting the minimum criteria of each (Technology/Commercialization) readiness level framework in a manner that maximizes the project's performance on the other readiness level framework.

We determine the minimum criteria based on logical and common sense understanding of technology development projects. For example, it is not logical to conduct pilots (CRL-4)

without first having the technology sub-system validated in relevant environment (TRL-5) or, preferably, having a prototype demonstration in a relevant environment (TRL-6). Similarly, attempting to design and validate a Minimum Marketable Product (CRL-5) without completing a prototype (TRL-6) is also illogical. Hence, these form the minimum criteria which determine that the 'optimum' path lies in conducting pilots after the sub-system or prototype is validated in the relevant environment, and then using the learning from the pilots to refine the prototype and design the Minimum Marketable Product.

Table 6: Second stage construction of the TCRM Matrix framework, with two test cases

TRL9									
TRL8									
TRL7							P1(t3)		
TRL6			P1(t2)						
TRL5				P2(t2)					
TRL4							P3(t2)		
TRL3	P1(t1)								
TRL2									
TRL1									
	CRL1	CRL2	CRL3	CRL4	CRL5	CRL6	CRL7	CRL8	CRL9

LEGEND								
	Concrete Idea		Commercial Lag (small)		Technological Lag (small)		Diffused Idea
	Optimum Path		Commercial Lag (large)		Technological Lag (large)		Not Possible, by definition

We again examine the two test cases using this stage of the TCRM Matrix framework, and find that:

- Between t1 and t2, the project P1 focused on technological development but did not meet its commercial readiness potential that could have been achieved at that stage. Then between t2 and t3, it shifted focus to commercial development but started lagging in the potential technology readiness that could have been achieved at that stage.
- At time t2, P1 has highest technological readiness but does not meet its commercialization readiness potential, while P3 has very high commercial readiness but does not meet its technological readiness potential. The project P2 has maximized its commercial readiness for the level of technological readiness

it had achieved.

At this stage the TCRM Matrix framework offers some additional insights through the joint assessment over and above that possible from a discrete assessment. However, these insights are not fully actionable, and do not highlight the risks or challenges associated with the technological or commercial lag in the technology development project. We also find that at this stage, the notion of the 'optimum path' is based purely on the interdependence of the TRL and CRL frameworks, and requires validation from the external framework.

6.3 Third Stage of Construction

In the third stage of construction of the TCRM Matrix framework we attempt to fill the gaps by incorporating the MRL framework (which we reiterate and emphasize is a framework based on extrinsic indicators) and overlaying it on the 'optimum path'. This is done by envisioning the MRL framework as a set of line segments that cut across the matrix based on the MRL framework's underlying linkages with the TRL and CRL framework.

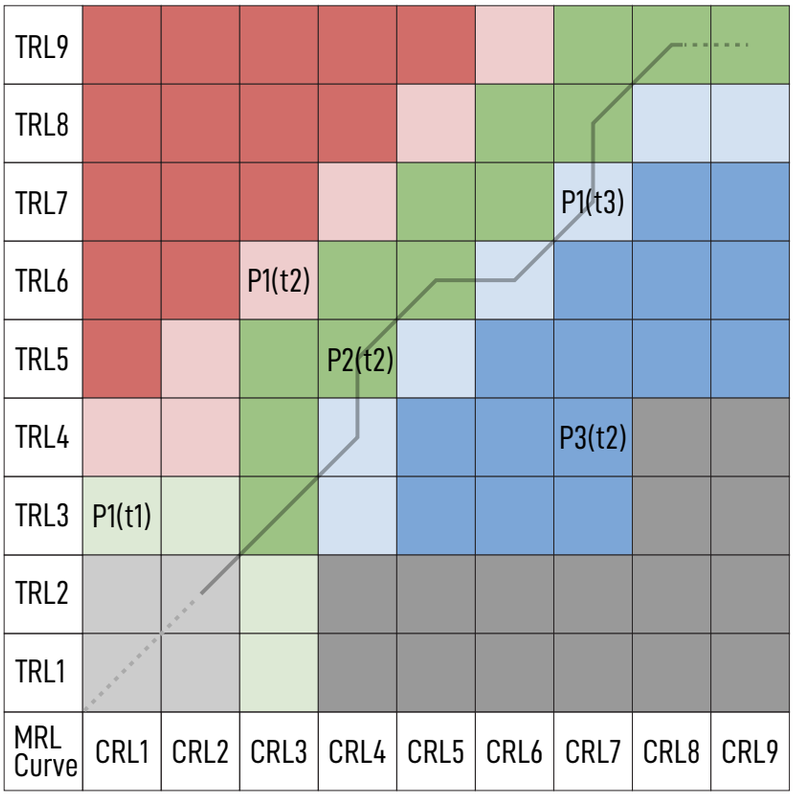
We first show the reimagined MRL framework overlaid on top of the Second Stage construction of the TCRM Matrix framework with each level placed and labelled in a corresponding cell. Here it is important that emphasize that unlike the TRL and CRL frameworks (as used in the TCRM) that identify the current status of the technology development project, the MRL framework (as used in the TCRM) identifies the minimum market readiness level that needs to be achieved to meaningfully proceed to the next technology readiness level or commercialisation readiness level.

Table 7: Second stage construction of the TCRM Matrix framework, overlaid with the MRL framework

TRL9								MRL 9	
TRL8							MRL 8		
TRL7							MRL 7		
TRL6					MRL 5	MRL 6			
TRL5				MRL 4					
TRL4				MRL 3					
TRL3			MRL 2						
TRL2		MRL 1							
TRL1									
	CRL1	CRL2	CRL3	CRL4	CRL5	CRL6	CRL7	CRL8	CRL9

This form of the TCRM Matrix framework is only an interim step intended to develop an understanding of the framework. Moving towards its final form, the MRL content in the cells of the matrix is replaced with basic line segments, and the resulting curve - called the MRL curve - is retained. In order to ensure ease-of-use, it is emphasized that the MRL curve increases by one 'level' every time it moves to the next cell in the matrix. It should also be noted that the direction of movement determines whether that minimum market readiness level enables achieving the next readiness level for technology (vertical movement), commercial (horizontal movement), or both (diagonal movement).

Table 8: Third and final stage construction of the TCRM Matrix framework, with two test cases



LEGEND		Concrete Idea	Commercial Lag (small)	Technological Lag (small)	Diffused Idea
/	MRL Curve	Optimum Path	Commercial Lag (large)	Technological Lag (large)	Not Possible, by definition
The MRL Curve increases by one 'level' every time it moves to the next cell in the matrix					

We again examine the two test cases using this stage of the TCRM Matrix framework, and find that:

- Between t1 and t2, the project P1 focused on technological development but did not meet its commercial readiness or the market readiness potential that could have been achieved at that stage of technology development. Then between t2 and t3, it shifted focus to commercial development but started lagging in the potential technology readiness that could have been achieved at that stage. However, in doing so, it moved closer to the market readiness for the given level

technology development, and at t3, achieved a more optimum balance between technological, commercial, and market readiness.

- At time t2, P1 has highest technological readiness but does not meet its commercialization readiness potential and is also lagging in market readiness. At the same time, P3 has very high commercial readiness but does not meet its technological readiness potential. Moreover, it has strayed far away from the market readiness, and therefore its high commercial readiness is unlikely to offer meaningful returns. The project P2 has not only maximized its commercial readiness for the level of technological readiness it had achieved, but also rides the market readiness curve closely thereby ensuring it is responsive to shifts in the market forces.

At this final stage, the TCRM Matrix framework offers more meaningful insights through the joint assessment (over and above that possible from a discrete assessment) and also offers actionable intelligence in each test case. Further, the optimum path based on the interdependence of the TRL and CRL frameworks (the intrinsic model) and the MRL curve (the extrinsic model) are found to track closely with each other. This validates and completes the notion of the optimal path, where projects that 'ride the curve' will be able to transition from the lab to market with greatest ease.

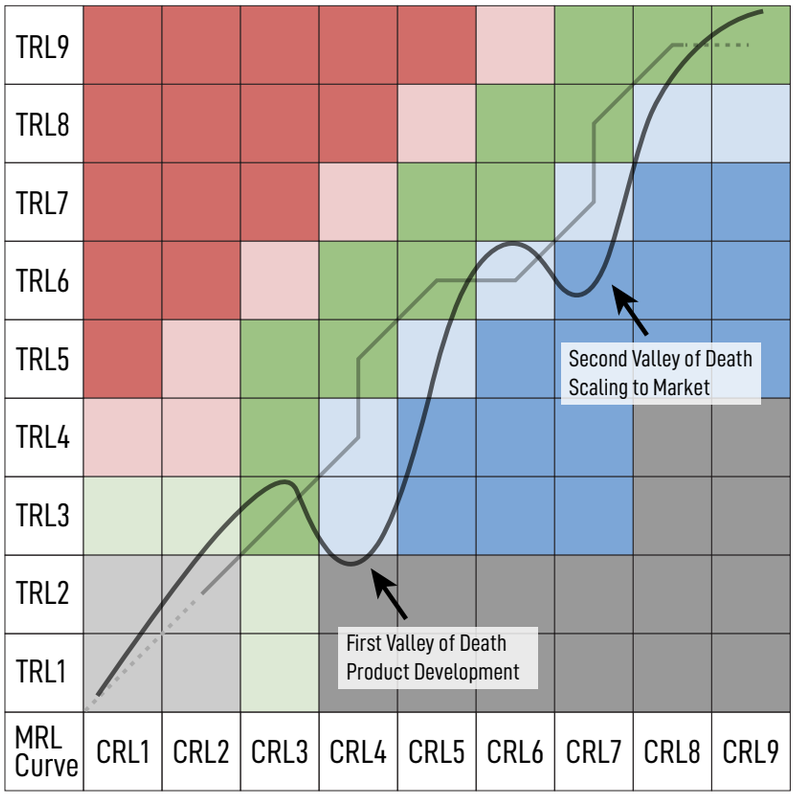
7. Validating the TCRM Matrix framework

The Techno-Commercial Readiness and Market Maturity Matrix (TCRM Matrix) framework has been constructed as a joint assessment framework on the basis of existing TRL, CRL, and MRL frameworks. In order to validate the TCRM Matrix framework, we take a two pronged approach. First, we compare the framework itself against external frameworks that are distinct from those used in its construction. And second, we examine how the results yielded by the framework when applied to established and broadly recognized successful technology development projects.

7.1 Validation Based on Other Models

Across the scientific, industrial, and startup community, the 'Valley of Death' framework is acknowledged as a time-tested model and has been found to be true across a wide range of technology development projects. Therefore, we attempt to validate our framework against it by superimposing the Valley of Death curve over the TCRM Matrix framework. Here, the Valley of Death curve is placed along the CRL framework.

Table 9: The TCRM Matrix framework validated against the Valley of Death Framework

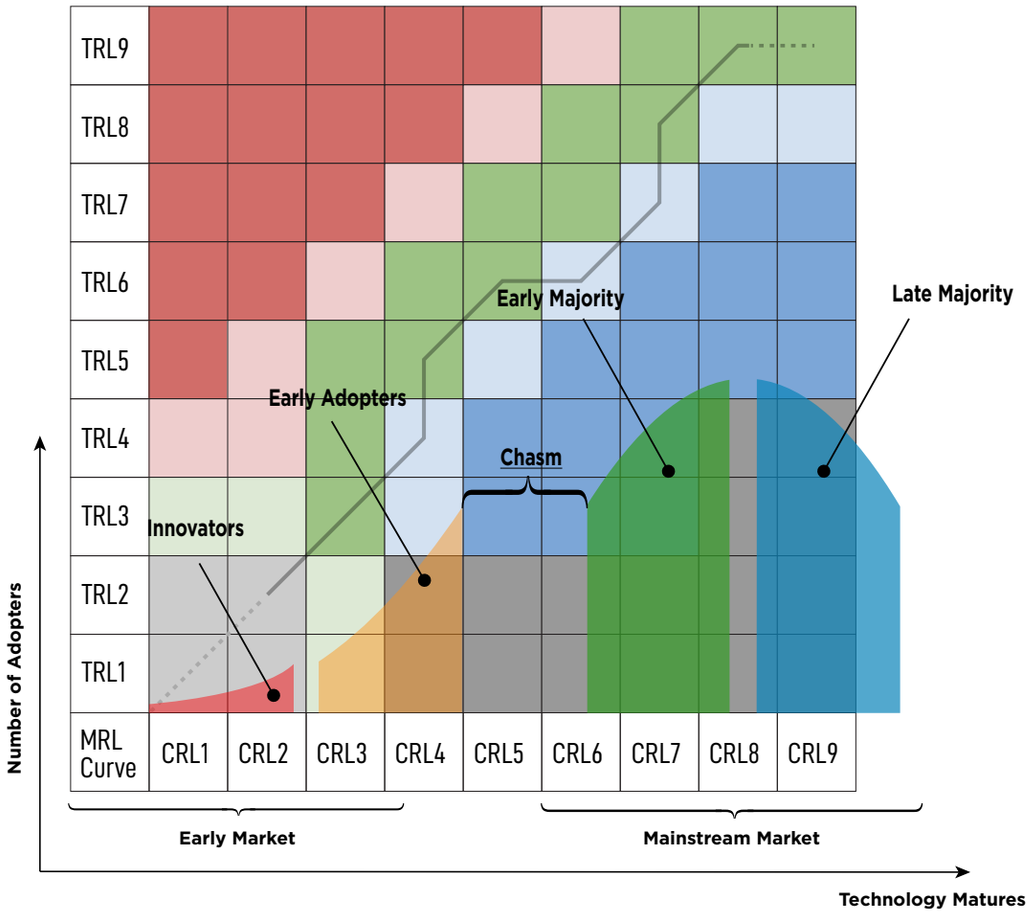


We note that the Valley of Death curve is loosely aligned with the MRL curve and the optimal path. There are two prominent 'valleys'; the first being that of Product Development and the second being that of Scaling to Market. Here it is highlighted that the optimal path

shown in the TCRM Matrix framework offers a smooth and efficient transition through the valleys, and encourages a market-aware approach to technology development.

Another important framework that is used in the context of assessing the status of technology development projects is Moore's Technology Adoption Life Cycle framework. This framework uses a sociological model and suggests that technology adoption in a group follows a Bell Curve. It states that Innovators and Early Adopters are eager enthusiasts to adopt new technology, but there being a 'chasm' before the Early Majority and Late Majority also adopt that technology. We attempt to validate the TCRM Matrix framework against Moore's Technology Adoption Life cycle Framework by superimposing them placed along the direction of time.

Table 10: The TCRM Matrix framework validated against the Technology Adoption Life Cycle Framework[34]



We observe that the Technology Adoption Life Cycle Framework extends beyond the TTCRM Matrix framework, but is aligned in terms of expected adoption under the framework. Here it is highlighted that the optimal path shown in the TCRM Matrix framework enables the transition through the 'chasm' by ensuring the feedback from Early Adopters (or Pilot Stakeholders in the TCRM Matrix framework) is incorporated in the product development to create a Minimum Marketable Product that can bring in the Early Majority.

Based on the validation against the two external frameworks, the TCRM Matrix framework appears to deliver consistent analytical insights with those frameworks.

7.2 Validation Based on Established Case Examples

We recognise that any assessment framework is only as good as the results and insights it provides. Hence, to determine the validity of its results as against the general consensus of what is considered a successful technology development project, we examine what results the TCRM Matrix framework would offer in respect of three very different examples of technology development projects–viz. BHIM UPI (a financial application of information and communication technology), COVAXIN (a vaccine developed in response to the COVID-19 pandemic), and the PSLV (an indigenously developed satellite launch vehicle). This is done by taking 5 milestones along the development of each project, plotting them on the TCRM Matrix framework, and examining whether the results produced are aligned with the general consensus of their performance.

Case Example 1*: The BHIM UPI system*

Important Milestones in the development of the BHIM UPI system:

M1 (October 2012) : UPI envisioned in "Payment Systems in India: Vision 2012-2015". Note that IMPS (Immediate Payment Services) had already been launched in 2010.

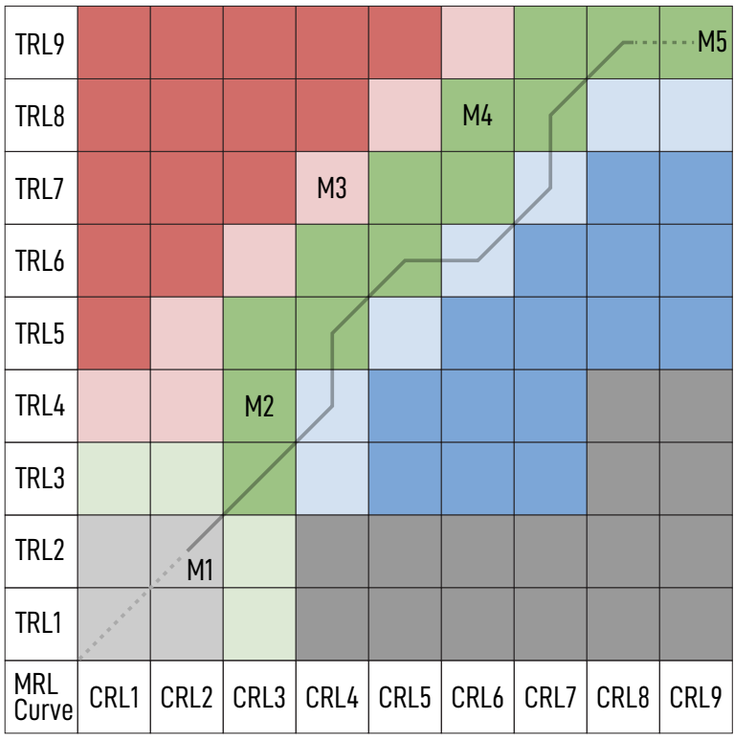
M2 (August 2014) : *99# service launched to build on IMPS and RuPay services

M3 (April 2016) : UPI pilot launched by RBI with 21 banks and BHIM UPI app launched

M4 (December 2016) : UPI-enabled apps are available across platforms

M5 (July 2021) : UPI starts being internationalized

Table 11: Milestones in development of UPI as plotted on theTCRM Matrix framework



United Payment Interface (UPI), is the flag-bearer of the ongoing Indian Financial Revolution. It is an instant real-time payment system developed by the National Payments Corporation of India (NPCI). The interface facilitates inter-bank peer-to-peer (P2P) and person-to-merchant (P2M) transactions.

The UPI journey began in 2012 when the Reserve Bank of India (RBI) released a vision statement for a period of four years that indicated commitment towards building a safe, efficient, and authorized payment and settlement system in India. As a next step, in the year 2014, *99# service was launched by NPCI, which is a USSD (Unstructured Supplementary Service Data) based mobile banking service that brings together diverse ecosystem partners such as Banks & TSPs (Telecom Service Providers). This marks an efficient jump in the technical and commercial levels as per theTCRM Matrix framework. The next milestone was achieved with the launch of the UPI pilot in April 2016, with 21 banks. This was followed by working on the feedback from the pilot of the UPI MVP and subsequent public launch in December 2016. These two milestones in the UPI development journey witness a steady and efficient rise in the technical maturity of the product and parallelly managing the commercialization timeline. The path followed by the product cycle is a little discordant with the TCRM Matrix framework which can be understood by the fact that it took almost two years for the UPI pilot launch. If the product journey would have followed the MRL key components of proper Market Research and Market Fit Validation, this could have been achieved a little earlier.

Finally, the last milestone sees a major jump in the commercial maturity of the UPI product/ brand. The NPCI International Payments Limited (NIPL) signed a memorandum of understanding (MoU) with a UK-based financial firm in 2021 to expand the acceptance of UPI into foreign markets especially in China and the United States which accounts for half of all international transactions coming from India. This marks the alignment with the TCRM Matrix framework.

Case Example 2: *The COVAXIN journey*

Important Milestones in the development of the Indian vaccine Covaxin:

M1 (May 2020) : Pre-clinical studies completed for the discovery of indigenous vaccine

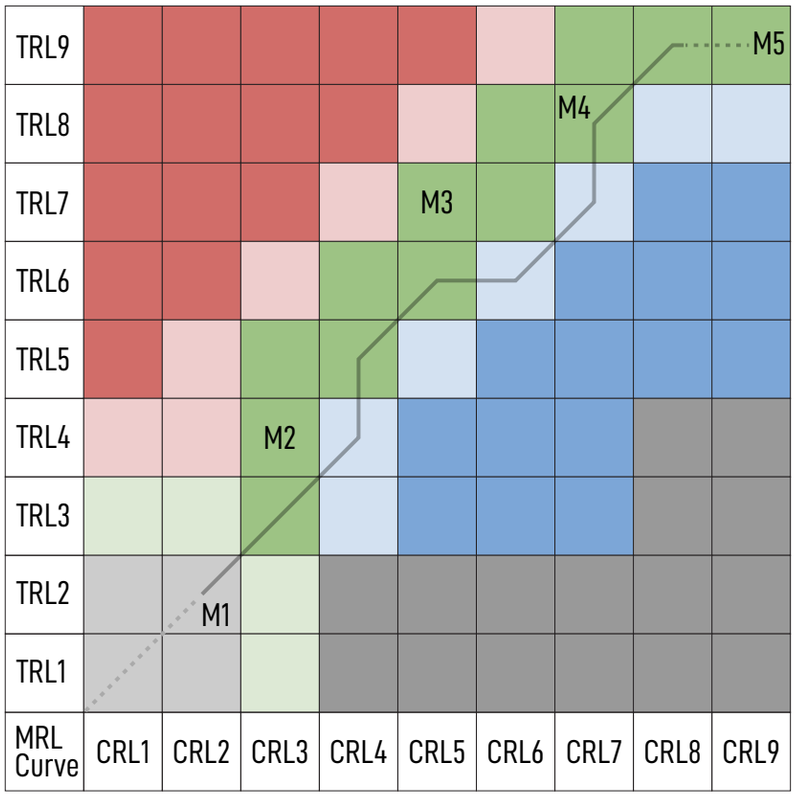
M2 (July 2020) : DCGI approval for Phase I & II Human Clinical Trials

M3 (November 2020) : Phase III Trials begin for the vaccine

M4 (January 2021) : Covaxin received Emergency Use Authorisation (EUA) from the DCGI for restricted use

M5 (November 2021) : Covaxin granted Emergency Use Listing by the World Health Organization (WHO)

Table 12: Milestones in development of Covaxin as plotted on the TCRM Matrix framework



When Covid-19 was declared a pandemic in March 2020, it was only a matter of time, and the virus had already taken over the whole world, not expected to leave anytime soon. As the world's pharmacy, India needed to play a major role in drug and vaccine development. Amidst a crisis and the resultant issues related to logistics, coordination and so on, India was able to roll out its indigenously developed vaccine at the beginning of 2021.

The Covaxin journey began in May 2020 with the announcement of the partnership between Bharat Biotech with the National Institute of Virology and the Indian Council of Medical Research to develop an inactivated coronavirus vaccine called Covaxin and the pre-clinical studies were completed subsequently. By the start of July 2020, India's Drugs regulatory body, DGCI (Drugs Controller General of India) gave Covaxin the go ahead for human trials. Next, in November 2020, the company announced that they were beginning phase 3 trials for the vaccine. This milestone is where the Covaxin development curve goes off the tangent as per the TCRM Matrix framework. This is because of the fact that in comparison to the typical 10-year-cycle of vaccine development, the development of covaxin in less than a year is nothing less than an extraordinary achievement and hence a major technical maturity surge is witnessed.

In January 2021, Covaxin received Emergency Use Authorisation (EUA) from the DCGI for restricted use which marks the next milestone in the vaccine development journey. The vaccine's efficacy results were released much later in March 2021 end which declared the vaccine to be "safe, immunogenic with no serious side effects". Following this, it was announced in September 2021 that Bharat Biotech has been submitting data from their clinical trials to the WHO on a rolling basis for a EUL (emergency use listing). And by

November 2021, the WHO officially announced that Covaxin has finally been added to its list of recognised and recommended vaccines. The major milestones in the development and commercialisation of the vaccine Covaxin establish that it is in sync with theTCRM Matrix framework.

Case Example 3*: The Polar Satellite Launch Vehicle (PSLV) journey*

Important Milestones in the development and launch of the Indian launch vehicle:

M1 (May 1978) : Studies by the PSLV Planning Group began

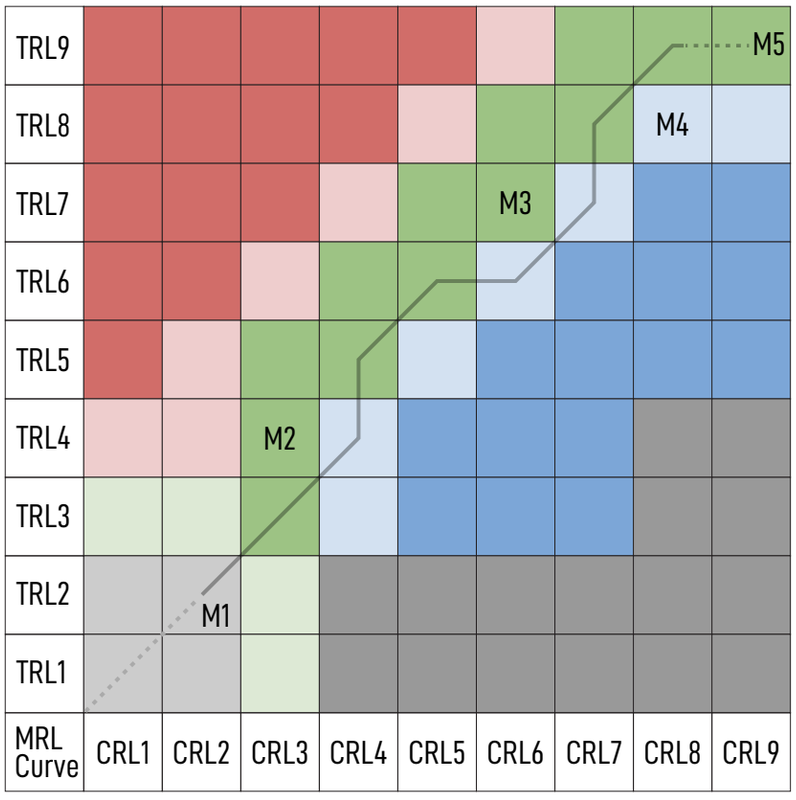
M2 (October 1994) : PSLV-D2 successfully launched IRS-P2

M3 (May 1999) : PCLV-C2, ISRO's first commercial launch with foreign satellites as payload

M4 (December 2020): PSLV-C50 injects communication satellite CMS-01 into orbit

M5 (September 2022) : Private Industry bagged contract for end-to-end realisation of five PSLVs over a period of four years

Table 13: Milestones in development of PSLV as plotted on the TCRM Matrix framework



The Polar Satellite Launch Vehicle (PSLV) is an expendable medium-lift launch vehicle designed and operated by the Indian Space Research Organisation (ISRO). It was developed to allow India to launch its Indian Remote Sensing (IRS) satellites into sun-synchronous orbits, a service that was only commercially available from Russia until the advent of the PSLV in 1993.

The major milestones in the development and scale-up of the PSLV through the years establish that it is in sync with the TCRM Matrix framework. Its development was initiated with studies by the PSLV Planning group to develop a vehicle that began in 1978. The PSLV was first launched in September 1993. While the first and second stages performed as expected, an attitude control problem led to the collision of the second and third stages at separation, and the payload failed to reach orbit. After this initial setback, the PSLV successfully completed its second mission in 1994, which has been marked as the second milestone in the PSLV journey.

The third milestone is the launch of the PCLV-C2, ISRO's first commercial launch with foreign satellites as the payload. It was for the first time that ISRO launched three satellites in a single vehicle – with the Indian Remote Sensing Satellite as the main payload and Korean and German as auxiliary payloads. This proves to be a steady increase in the technical maturity and commercial success of the product, and shows a market readiness in the development of the PSLV. The next milestones of launching the PSLV-C50 which injects communication satellite CMS-01 into orbit and eventually the allocation of contracts for the end-to-end realization of PSLVs to the private industry see a significant increase in the technical and commercial levels which is in agreement with the TCRM Matrix framework.

8. Using The Techno-Commercial Readiness and Market Maturity Matrix (TCRM Matrix) Framework

Over the previous sections, the Techno-Commercial Readiness and Market Maturity Matrix (TCRM Matrix) Framework has been developed and validated as a tool for the joint assessment of the technical, commercial, and market readiness of technology development projects. This section focuses on using the TCRM Matrix framework, discussing where it is best used, explaining how it is used, and highlighting what to understand from its use.

As briefly touched upon when discussing the need for assessing tech-based projects, the first step in any assessment must be determining what kind of project is being assessed. While there are multiple paradigms for classification of such projects, we find that the Quadrant Model of Scientifc Research proposed by Donald Stokes offers a simple, intuitive, and effective framework for classification. The framework (see figure below) essentially asks two questions for any project: Is there a quest for fundamental understanding? And is there a consideration for use? The project can then be classified as pure basic research (Bohr Quadrant), pure applied research (Edison Quadrant), or use-inspired basic research (Pasteur's Quadrant).

Quadrant Model of Scientifc Research

		Is there a consideration for use?	
		No	Yes
Is there a Quest for fundamental understanding?	Yes	Pure Basic Research *Bohr Quadrant*	Use-inspired Basic Research *Pasteur Quadrant*
	No	*Other Quadrant*	Pure Applied Research *Edison Quadrant*

Figure 4: *Quadrant Model of Scientific Research by Donald Stokes*

The methodology of classification proposed in this model already indicates that scientific projects in different quadrants will have to be assessed differently. Keeping in mind that the TCRM Matrix framework is envisioned and developed for joint assessment, it would be best suited for the assessment of projects that have some consideration of use, i.e., the projects that come under the Pasteur Quadrant and Edison Quadrant.

As seen from the test cases, the TCRM Matrix framework can be used to assess the progress of technology development projects over time or to comparatively assess different technology development projects at a given point of time. In both cases, the usage involves plotting the status of projects on the matrix as well as on the MRL Curve using independent assessments. Here, it is advised that the independent assessments be conducted keeping in mind the technological and economic context of the technology development project.

Recalling the discussion on the need for assessments, it is highlighted that the most prominent case is the examination of individual technology development projects. In order to effectively leverage the TCRM Matrix framework, the status of any project at multiple points of time since its inception should be considered (or in case of proposals, the important milestones along its development should be considered). Then, the project can be assessed with the following steps:

1. An independent assessment of the technological and commercial readiness of the project is undertaken at each point of time, and these are plotted onto the matrix. For improved results, an independent assessment of the market maturity is undertaken at each of those points, and plotted on the MRL Curve with a link to its corresponding status on the matrix.
2. The direction of the project's progress over time (formed by the plotted status at each point of time) is considered relative to the direction of the optimal path. This is used to determine whether the project is maximizing its commercial readiness for a given level of technological readiness, and vice-versa.
3. The distance of the project's status from the MRL Curve at each point of time is considered to determine what gaps the project needs to fill in order to maximize its commercial readiness for that status level of technological readiness.

The other case is the comparative assessment of different technology development projects at a given point of time. In order to gain meanginful insights from a comparison using the TCRM Matrix framework, it is suggested that the projects be generally similar in terms of scope and objectives. Then, the projects can be comparatively assessed with the following steps.

1. An independent assessment of the technological and commercial readiness is undertaken for each project, and these are plotted onto the matrix. For improved results, an independent assessment of the market maturity of each project is undertaken, and is plotted on the MRL Curve with a link to its corresponding project on the matrix.
2. The position of each project on the matrix is used to determine whether the project is on or near the optimal path or is technologically or commercially lagging, and the extent of such a lag.
3. The distance of each project from the MRL Curve is considered to determine the project closest or farthest from market maturity, and to ascertain the steps required to reach market maturity for them.

In this manner, the TCRM Matrix framework provides additional insights beyond independent assessment and also gives actionable intelligence for the effective progress of the technology development project.

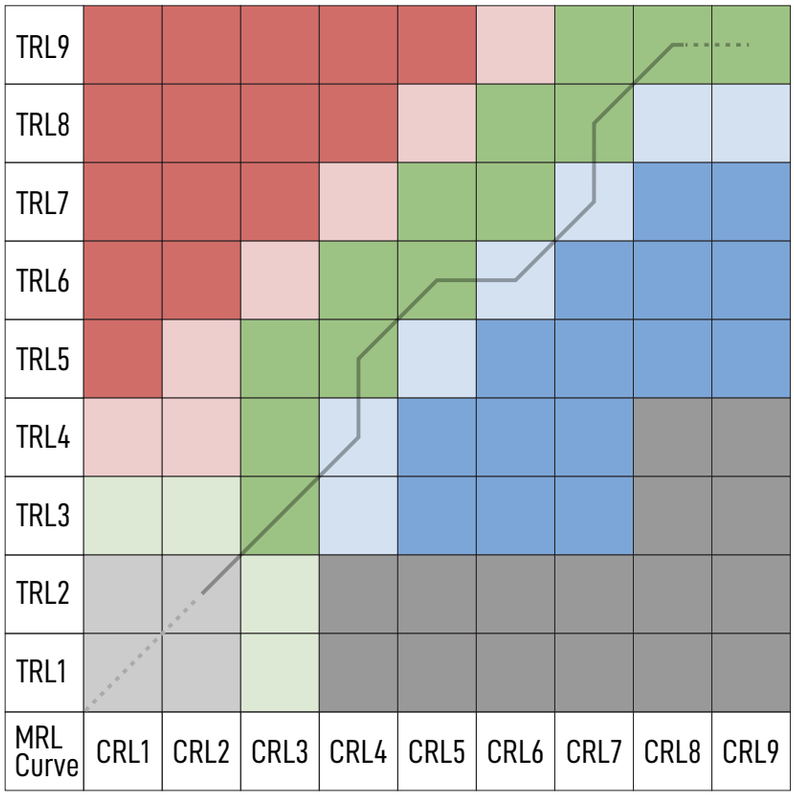
Interpreting the TCRM Matrix framework is an integral component of its usage, and to that end, an attempt has been made to use the matrix, the colours coded portions, and the curve to make it intuitive to understand. The most important interprtive note is that the TCRM Matrix framework is inclined towards commercialisation by design, so as to nudge the technologies being developed to enter the market. A project that is travelling along the optimal path and riding the MRL Curve will have a higher likelihood of success and will

reach the market the fastest.

Moreover, a project that is commercially lagging will draw little benefit from the technological progress, and will most likely have to revisit its product designs and the product-market fit. A project that is technologically lagging will draw little benefit from the commercial progress, and will most likely have to revisit its technology development. The status of any project plotted on the matrix gives a simultaneous view of the project's progress along the technological and commercial dimensions. The distance (in terms of cells) of the status plotted on the matrix and the status plotted on the MRL Curve (or just the closest point on the MRL Curve) gives the market maturity gap.

However, as with all other frameworks, the TCRM Matrix framework is a tool to simplify and visualise the complex conditions of the real world in which the technology development project is being implemented. Hence, with scientific humility, we suggest that a modicum of caution must be exercised when drawing such inferences and conclusions. At the same time, we also firmly believe the joint assessment framework offers significant advantage over other independent assessment tools.

Table 14: The TCRM Matrix framework and its Legend



LEGEND		Concrete Idea	Commercial Lag (small)	Technological Lag (small)	Diffused Idea
/	MRL Curve	Optimum Path	Commercial Lag (large)	Technological Lag (large)	Not Possible, by definition
The MRL Curve increases by one 'level' every time it moves to the next cell in the matrix					

9. Value Proposition of the TCRM Matrix Framework

The TCRM Matrix framework has been designed to have a high level of abstraction, so that it may be applied to a wide range of technology development projects, and will encourage ease-of-use, so that a user would be able to intuitively utilize it without prior knowledge. In doing so, the TCRM Matrix framework offers important value for a wide range of stakeholders.

9.1 Government

1. **Prioritizing Funding:** It is particularly important as it can help in making informed decisions about funding research and development projects. By using TCRM Matrix assessments, governments can prioritize investments in technologies that are ready for commercialization and have the potential to create new markets, drive innovation, and spur economic growth. By investing in and supporting these technologies, governments can help create new jobs and drive economic development.
2. **Risk Mitigation:** The TCRM Matrix assessments can help the government identify potential risks associated with any existing or new upcoming technology and develop strategies to mitigate those risks. The government can determine its potential market size, competitive landscape, and potential barriers to adoption.
3. **Setting Regulations:** The TCRM Matrix assessments can help the government set appropriate regulations for emerging technologies. The government can use TCRM Matrix assessments to determine the appropriate level of regulation required to ensure the safety and reliability of the technology as well as can help accelerate the commercialization of new technologies and reduce the time and cost of bringing them to market.
4. **Public-Private Partnerships:** The TCRM Matrix assessments can help the government establish public-private partnerships to develop and commercialize new technologies. By providing funding for technologies with high TRL levels, the government can incentivize private sector investment and accelerate the commercialization of new technologies.
5. **Strategic Planning:** The TCRM Matrix assessments can help the government develop strategic plans for technology development and deployment. By understanding the TRL levels of different technologies and assessing the readiness to be scaled

up, the government can prioritize investments in areas where there is a high potential for impact and where the technology is most likely to be successful.

9.2 Academia

1. **Understanding Project Viability:** The TCRM Matrix assesses the current state of a project and helps in identifying the project weaknesses and next steps. It demonstrates the current status of products for market launch and understanding of barriers to exploitation/sustainability based on the viability of project outputs.

- **Effort and Cost Estimation:** The TCRM Matrix can help in understanding the context, anticipated value and impact, and credibility of the execution plan of the project. Used that way, TCRM can be used to assess the project's applicability, capacity and tenacity of delivering the desired results.
- **Transitioning Technologies:** The TCRM Matrix approach can be seen as an important toolkit in its research and innovation strategy; developing a more robust pathway for the transition of technologies from laboratory to market, commercialization and R&D funding.
- **Problem-Solution Fit Check:** The TCRM Matrix can be used to evaluate the potential of the product to be scaled from laboratory to pilot scale and issues that may affect achieving full scale can be identified. Furthermore, mapping the product attributes against customer needs with a clear value proposition.
- **Facilitating Collaboration:** The TCRM Matrix can facilitate collaboration between different sectors, such as the government, industry, and academia. By using a common language and framework for assessing technology readiness, academia can better communicate with the various stakeholders and work together towards achieving shared goals.

9.3 Industry & Startups

1. **Internal Project Planning:** As an industry or startup, determining the direction of work in every project is a crucial and periodic activity. The TCRM Matrix serves as a handy tool for reviewing progress so far and determining next steps for a given project or multiple projects. Moreover, it also helps in ensuring an efficient utilisation of existing funds and resources.

2. **Technology Transfer or Acquisition**: A key decision taken during a large technology development project is whether to transfer or acquire a given technology. The TCRM Matrix can be used to make an informed decision about such a transfer or acquisition, providing not only the current status but also a quick estimate of the steps to be taken before that transfer or acquisition begins providing results.
3. **Improved Funding and Financing**: Both as an industry or as a startup, obtaining funds to finance ongoing or planned projects is an important activity that determines their valuation. The TCRM Matrix can be used to validate the assumptions and provide robust valuation of the technology development project at each stage. This not only boosts the valuation, but also provides confidence to all stakeholders.
4. **Go-To-Market Strategy**: Every product and every market is different, and developing a strategy for going to market requires a thorough analysis of the product-market fit along with iterative product development. The TCRM Matrix can be used to provide a clear roadmap towards such a strategy for each product, whether as a new technology or as an established technology entering a new market.
5. **Tracking Emerging Technologies**: Keeping track of emerging technologies is important for industries and startups whose core value proposition is based on technology development. Here, the TCRM Matrix offers a quick tool to determine which technologies are closest to market and can cause disruption to the existing order of business.

9.4 Investors

1. **Support for Portfolio Companies:** The TCRM Matrix can be used by investors to evaluate the commercialization and market readiness of their portfolio companies. The framework will also help them identify the key gaps for their growth and thereby accelerate the progress of their portfolio companies. Moreover, the TCRM Matrix framework also serves to validate the valuation assumptions for these companies.

2. **Informed Investment Decisions**: The TCRM Matrix can be used to assess innovations and startups that are pitched to them. Investors can determine the approach to product development undertaken until that point. Moreover, the framework can also help them explore pathways for the innovation or startups to enter the market, and the steps that need to be taken in those pathways.
3. **Improving Resource Utilization**: The efficient utilization of existing resources is crucial for the survival of an innovation or startup. As investors, the TCRM Matrix will provide a quick and reliable reference to improve the utilisation of resources

in a manner that will accelerate that innovation or startup to the market.

4. **Determining Scalability**: The TCRM Matrix enables an assessment of the scalability potential of an innovation or startup at a given point based on its distance from the MRL curve. This can be a key indicator for an investor to determine where to focus their attention among their portfolio companies and what is needed for that innovation or startup to achieve scale.

5. **Planning Exit Strategy**: As an investor, the logical conclusion of their involvement with an innovation or startup is their exit, and hence, planning for it is imperative. The TCRM Matrix can be used to explore various exit points along the innovation or startup's journey, and determine the potential Return on Investment value at the point of exit.

10. Conclusion & Way Forward

Whereas there are a large number of frameworks that focus on one aspect for assessment, the insights they offer are limited in their scope. Hence, there is a need to encourage simultaneous assessment of technological, commercial, and market readiness. We note that there have been a few efforts around the globe to create such frameworks for joint assessment of technology development projects, but we found that either such frameworks are not intuitive or they do not offer additional insights in the form of joint assessment.

The proposed TCRM Matrix framework seeks to fill these gaps through a joint assessment, which will offer meaningful insights, and introduce the notion of an optimal path, which gives actionable intelligence. At the same time, we recognize that all frameworks are an estimation of the larger picture, and while we have made our best efforts to ensure that a holistic estimation is provided through the proposed TCRM Matrix framework, we caution that it is not a replacement to human intelligence inputs.

Overall, the Techno-Commercial Readiness and Market Maturity Matrix (TCRM Matrix) framework is an important tool for all the stakeholders of a nation involved in technology development and innovation landscape such as the government, academia, industry & startups as well as the investor community. The TCRM Matrix can be useful in promoting innovation, reducing risk, and achieving economic and social benefits. In particular for the government, we highlight that this framework can be used to make informed decisions about investments, policies, and regulations.

The goal of this paper is to provide an improved understanding and assessment methodology for technology development projects, and in turn, help more indigenous innovations reach Indian as well as International markets. It is acknowledged that as the framework is used by various stakeholders some challenges in its usage may emerge, which will be incorporated and addressed in the future. Further, it has been recognised that this is only one aspect towards improving the Quality of Science and Ease of Doing Science in India.

In closing, it is emphasized that the role of a scientist and innovator is not simply the discovery or creation of a technology, but also includes the responsibility of ensuring that the technology is being applied for the socioeconomic development of the nation.

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12. About the Authors

Dr. V.K. Saraswat, Member (S&T), NITI Aayog

Dr Vijay Kumar Saraswat, Padma Bhushan (2013), is a distinguished scientist with vast experience in defence research—in both basic and applied sciences—spanning several decades. As the Member (S&T), NITI Aayog, he has spearheaded programmes for the development of the Methanol Economy, Carbon Capture Utilisation and Storage, and Nuclear Small Modular Reactors.

Dr. Neeraj Sinha, Senior Adviser (S&T), NITI Aayog

Dr Neeraj Sinha has been working for over three decades on a broad cross-section of renewable energy, climate change, and material sciences. As the Senior Adviser (S&T), NITI Aayog his most notable work includes the Development of the Advanced Ultra Supercritical Technology for coal-based power generation and supporting the Atal Innovation Mission.

Sh. Naman Agrawal, Specialist (S&T), NITI Aayog

Naman Agrawal is a result-oriented professional with over 10 years of experience across Startup Ecosystem Management and Technology Commercialization. As a Specialist (S&T), NITI Aayog, he has contributed to strengthening the science, technology and innovation ecosystem in the country in association with Central Scientific Departments/ Agencies, and has written 20+ academic and research articles.

Ms. Naba Suroor, Associate (S&T), NITI Aayog

Naba Suroor is a Science & Technology Policy professional with diverse experience in curriculum development and innovation management. As an Associate (S&T), NITI Aayog, she has provided policy inputs for the Quantum Computing Mission, National Science, Technology and Innovation Policy (STIP), and supported initiatives for the Global Innovation Index and the India Innovation Index.

Sh. Siddhey G Shinde, Young Professional (S&T), NITI Aayog

Siddhey G Shinde is a mission-driven Science & Technology Policy professional skilled in technology-aware Policymaking, International Regulations, and Strategic Partnerships. As a Young Professional (S&T), NITI Aayog, he has contributed to policies on the semiconductor ecosystem in India, telecom regulations, 5G spectrum and private networks, data protection, and the space economy.

सत्यमेव जयते

NITI Aayog

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