Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

IPR & TT Cell

A Guide on Technology Readiness Levels (TRL)

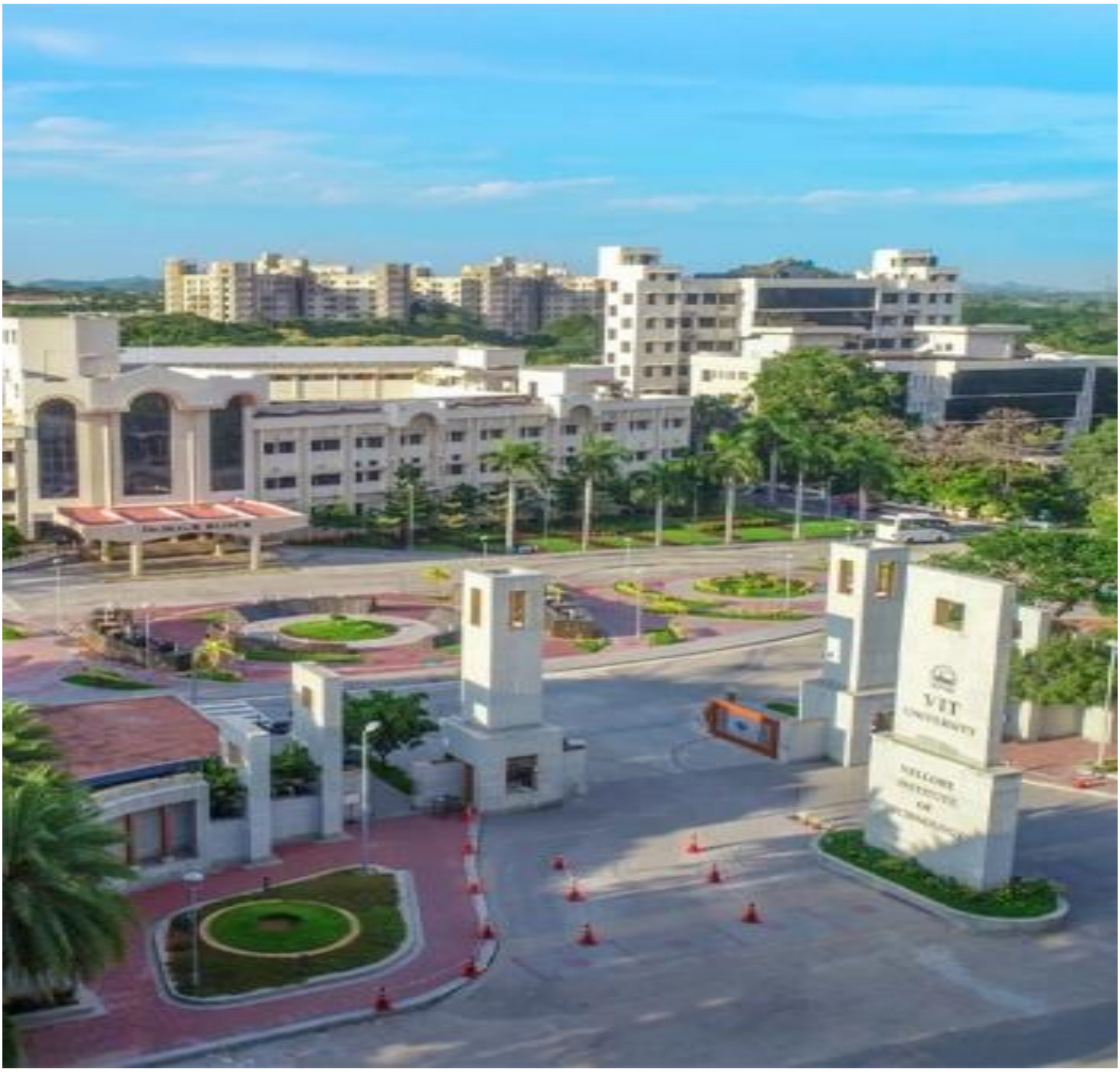

TABLE OF CONTENTS

****

I. Technology Readiness Levels Explanations

- Technology Readiness Levels (TRLs) are a metric system used to assess the maturity of a particular technology. Developed by NASA in the 1970s, the TRL scale has since been adopted by various government agencies and industries worldwide to provide a common understanding of a technology's status, manage risk, and make informed decisions about funding and development.
- The scale ranges from 1 to 9, where TRL 1 represents the earliest stage of research and TRL 9 signifies a fully proven and deployed system. Each level is defined by specific criteria that a technology must meet to advance.
- The TRL scale can be broadly grouped into three stages: research, development, and deployment.

II. Research Stage (TRL 1-3)

- **TRL 1:** Basic Principles Observed. This is the earliest stage of a new technology. Research is focused on a scientific discovery, and the basic principles are being studied and reported. The application is often theoretical.
- **TRL 2:** Technology Concept Formulated. Once the basic principles are established, the practical applications of the technology are identified. This stage involves analytical studies and defining the concept, but there's no experimental proof yet.
- **TRL 3:** Experimental Proof of Concept. Active research and development begins. Studies and lab measurements are conducted to validate the analytical predictions of the technology's individual components. A proof-of-concept model may be built.

III. Development Stage (TRL 4-6)

- **TRL 4:** Technology Validated in Lab. The basic technological components are integrated and tested together to ensure they work as a system. This happens in a controlled laboratory environment. The results show that the technology's performance targets may be attainable.
- **TRL 5:** Technology Validated in a Relevant Environment. The technological components are integrated with more realistic supporting elements and tested in a simulated environment. This is a significant step, as the reliability of the technology increases.
- **TRL 6:** Technology Demonstrated in a Relevant Environment. A prototype system is built and demonstrated in an environment that is a close simulation of the real operational environment. This represents a major increase in the technology's readiness.

IV. Deployment Stage (TRL 7-9)

- **TRL 7:** System Prototype Demonstration in an Operational Environment. The prototype is tested in its actual operational environment (e.g., a drone prototype is flown outside, or a new software system is tested by a limited number of real users). This is the last step before full qualification.
- **TRL 8:** Actual System Completed and Qualified. The technology is in its final form, has been qualified through tests and demonstrations, and is ready for manufacturing or deployment.
- **TRL 9:** Actual System Proven in Operational Environment. The technology is fully mature and has been successfully used in its intended operational environment. It has been "flight proven" or is ready for full commercial deployment.

V. TRL level example for Mechanical Engineering:

TRL Level		Description
TRL 1	Basic Principles Observed	A scientist publishes a paper on a new composite material with unique strength-to-weight properties, proposing its theoretical potential for use in aerospace structures.
TRL 2	Technology Concept Formulated	A mechanical engineer, after reviewing the TRL 1 paper, sketches a preliminary design for a drone propeller using the new composite material. They perform initial calculations and simulations to estimate performance, but no physical work is done.
TRL 3	Experimental Proof of Concept	A lab team builds and tests small, simplified specimens of the composite material to measure its tensile strength and fatigue life. The tests confirm the material's basic properties and its potential for a propeller.
TRL 4	Technology Validated in Lab	A small-scale, non-flying propeller is built from the composite material. It is tested in a wind tunnel under controlled lab conditions to see if it can withstand the forces and vibrations it would experience in flight.
TRL 5	Technology Validated in Relevant Environment	The propeller prototype is mounted on a test rig that simulates the flight environment of a drone. It is exposed to simulated wind, temperature, and pressure changes to validate its performance under more realistic, yet controlled, conditions.
TRL 6	Technology Demonstrated in Relevant Environment	A fully functional, but not-yet-optimized, drone prototype is built with the new composite propellers. It is flown in a controlled outdoor test range (the "relevant environment") to demonstrate its flight capabilities and the propellers' durability.
TRL 7	System Prototype Demonstration in an Operational Environment	The drone, now an advanced prototype, is used for a real-world task, like surveying a construction site. This demonstrates the technology's performance under actual operating conditions and by real users, but still in a controlled test phase.
TRL 8	Actual System Completed and Qualified	The drone design is finalized and passes all regulatory and safety certifications. A pilot production run is completed, and the drone is officially qualified for commercial sale and use.
TRL 9	Actual System Proven in Operational Environment	The drone is sold to a customer and is used for its intended purpose, such as package delivery, for an extended period. The technology is considered "proven" because it has a successful track record of real-world use.

VI. TRL level example for Electronics Engineering:

TRL Level		Description
TRL 1	Basic Principles Observed	A physicist discovers a new type of superconductor and publishes a paper on its electrical properties. This is a fundamental scientific finding.
TRL 2	Technology Concept Formulated	An electrical engineer identifies the potential of the new superconductor to be used as a component in a high-speed processor. They perform theoretical calculations and simulations to define the conceptual architecture of the processor.
TRL 3	Experimental Proof of Concept	A small, simplified circuit is built using the new superconducting material. The circuit is tested in a lab to verify that it can indeed carry current with minimal resistance at the required operating temperatures, proving the basic concept.
TRL 4	Technology Validated in Lab	The basic components of the processor—like a logic gate and a memory cell—are fabricated using the new material and integrated into a prototype board. The board is tested in a controlled lab environment to show that the components work together as intended.
TRL 5	Technology Validated in Relevant Environment	The prototype processor board is placed inside a cryogenic chamber that simulates the temperature and pressure conditions of its intended operational environment (e.g., a supercomputer's cooling system). It is tested to ensure it can function reliably under these conditions.
TRL 6	Technology Demonstrated in Relevant Environment	A full-scale prototype of the processor is built and integrated into a test computer system. This system is run through a series of demanding tasks and benchmarks to demonstrate the processor's performance and stability under conditions that closely mimic its real-world use.
TRL 7	System Prototype Demonstration in an Operational Environment	A working version of the supercomputer with the new processors is installed in a real data centre. It is used to perform a specific computational task for an extended period, demonstrating its viability and performance in a live, operational setting.
TRL 8	Actual System Completed and Qualified	The processor design is finalized, manufacturing processes are established, and the finished product passes all quality control and regulatory certifications. The final system is ready for mass production and commercial deployment.
TRL 9	Actual System Proven in Operational Environment	The new supercomputer with the advanced processors is sold to clients and has a track record of successful, reliable operation over a long period. The technology is now considered fully mature and proven.

VII. TRL level example for Electrical Engineering:

TRL Level		Description
TRL 1	Basic Principles Observed	A physicist discovers a new type of semiconductor material with unique electrical properties and publishes a paper on its potential.
TRL 2	Technology Concept Formulated	An electrical engineer reviews the research and develops a theoretical concept for a high-efficiency solar cell using the new semiconductor.
TRL 3	Experimental Proof of Concept	A lab team builds a small, simplified prototype of the solar cell to test its basic functionality and measure its efficiency under controlled conditions.
TRL 4	Technology Validated in Lab	The basic solar cell components are integrated into a small array and tested in a laboratory setting to confirm they work together and meet initial performance goals.
TRL 5	Technology Validated in Relevant Environment	The solar cell array is installed on a simulated rooftop (e.g., in a controlled lab with a solar simulator) and tested under varying light and temperature conditions to mimic its real-world use.
TRL 6	Technology Demonstrated in Relevant Environment	A full-scale prototype of the solar panel is installed on a test building or a small power grid and monitored for its performance and durability over several months.
TRL 7	System Prototype Demonstration in an Operational Environment	The solar panel system is deployed on a real home or commercial building and used by real customers. Its performance is monitored in this operational environment to confirm its reliability.
TRL 8	Actual System Completed and Qualified	The solar panel design is finalized and passes all industry and safety certifications (e.g., UL, IEC). The manufacturing process is established, and the product is ready for mass production.
TRL 9	Actual System Proven in Operational Environment	The solar panels have been successfully used by numerous customers for an extended period, demonstrating a strong track record of reliable and efficient energy production.

VIII. TRL level example for Computer Science and Engineering:

TRL Level		Description
TRL 1	Basic Principles Observed	A computer scientist publishes a theoretical paper on a new algorithm for quantum computing, outlining its fundamental principles and potential.
TRL 2	Technology Concept Formulated	A software engineer develops a conceptual design for a quantum-resistant encryption protocol based on the algorithm from TRL 1. They perform a security analysis and define the high-level architecture.
TRL 3	Experimental Proof of Concept	A team writes a basic code prototype of the encryption algorithm to test its core functionality and confirm it works on a small-scale data set in a simulated environment.
TRL 4	Technology Validated in Lab	The algorithm is integrated into a larger software module and tested with a variety of data types and sizes within a controlled lab environment to evaluate its performance and efficiency.
TRL 5	Technology Validated in a Relevant Environment	The software module is deployed on a private cloud server, simulating a real-world network environment. It is subjected to various network conditions and cyberattack simulations to assess its robustness.
TRL 6	Technology Demonstrated in a Relevant Environment	The quantum-resistant encryption software is integrated into a prototype messaging application and used for secure communication between a small groups of users in a test network.
TRL 7	System Prototype Demonstration in an Operational Environment	The messaging application is released to a limited number of actual users in a beta program. The system's performance, security, and usability are monitored and refined based on real-world feedback.
TRL 8	Actual System Completed and Qualified	The encryption software and the messaging application are finalized, fully documented, and pass all security audits. The product is ready for general release to the public.
TRL 9	Actual System Proven in Operational Environment	The messaging application is launched, widely adopted by users, and has a proven track record of providing secure, reliable communication over an extended period without significant security breaches.

IX. TRL level example for Civil Engineering:

TRL Level		Description
TRL 1	Basic Principles Observed	A materials scientist publishes research on a new self-healing concrete, detailing the chemical reaction that allows it to repair micro-cracks.
TRL 2	Technology Concept Formulated	A civil engineer proposes using the self-healing concrete to reduce maintenance costs for bridge decks. They develop a conceptual design and perform initial stress analysis to see if the material is feasible for structural use.
TRL 3	Experimental Proof of Concept	The engineering team creates small laboratory samples of the self-healing concrete. They induce tiny cracks and observe under a microscope how the material reacts, verifying the self-healing mechanism.
TRL 4	Technology Validated in Lab	A scaled-down model of a bridge deck section is cast using the new concrete. The model is subjected to controlled load cycles in a lab to simulate traffic stress, and its self-healing performance is validated under these conditions.
TRL 5	Technology Validated in a Relevant Environment	A full-sized beam made from the self-healing concrete is cast and placed in an outdoor test facility. It is exposed to real-world weather, temperature fluctuations, and cyclic loading to see how it performs outside of a controlled lab setting.
TRL 6	Technology Demonstrated in Relevant Environment	A small test section of a non-critical roadway or a sidewalk is paved with the new concrete. Engineers monitor its performance over a period of a year to observe its durability and self-healing properties under real, low-risk traffic and environmental conditions.
TRL 7	System Prototype Demonstration in an Operational Environment	A full bridge deck on a secondary road is replaced with the new self-healing concrete. Its performance is monitored continuously through sensors to ensure it meets structural integrity standards while in active service.
TRL 8	Actual System Completed and Qualified	The self-healing concrete has been fully tested and approved by state and federal transportation agencies. All manufacturing and construction standards are in place, and the material is ready for widespread use on public infrastructure projects.
TRL 9	Actual System Proven in Operational Environment	The new concrete has been used in multiple major projects, such as highways and bridges, for several years, demonstrating a consistent track record of reducing maintenance needs and extending service life.

X. TRL level example for Biotechnology:

TRL Level		Description
TRL 1	Basic Principles Observed	A scientist publishes a paper on a new protein identified in a microorganism that shows potential for a novel therapeutic effect.
TRL 2	Technology Concept Formulated	A team of biotechnologists reviews the research and develops a theoretical concept for using this protein as a drug to treat a specific disease. They define the mechanism of action and potential delivery methods.
TRL 3	Experimental Proof of Concept	The protein is isolated and purified in a laboratory. It is tested on cell cultures to verify its biological activity and confirm that it produces the desired effect in a simplified, controlled environment.
TRL 4	Technology Validated in Lab	A drug prototype is developed with the protein and tested on a small animal model (e.g., mice). The study confirms the drug's safety and efficacy under lab conditions.
TRL 5	Technology Validated in a Relevant Environment	The drug prototype is tested on a larger animal model, one that more closely mimics the human disease (e.g., primates). The tests are conducted to see how the drug is metabolized and to confirm its therapeutic effect in a more complex biological system.
TRL 6	Technology Demonstrated in Relevant Environment	The drug is produced in a clinical-grade facility, and a pilot study is conducted on a small number of human volunteers to assess its safety and dosage. This is the first step of a formal clinical trial.
TRL 7	System Prototype Demonstration in an Operational Environment	The drug enters Phase II clinical trials with a larger group of patients. The study demonstrates the drug's effectiveness and safety profile in its intended operational environment (i.e., treating the target patient population).
TRL 8	Actual System Completed and Qualified	The drug successfully completes Phase III clinical trials, and all regulatory approvals (e.g., FDA) are obtained. The manufacturing process is validated, and the drug is ready for commercial production.
TRL 9	Actual System Proven in Operational Environment	The drug is on the market and has been used by a large number of patients for an extended period, demonstrating a strong track record of safety and efficacy in the real world.

XI. TRL level example for Chemical Engineering:

TRL Level		Description
TRL 1	Basic Principles Observed	A chemist publishes a study on a new catalytic material that shows a theoretical potential to increase the yield of a chemical reaction.
TRL 2	Technology Concept Formulated	A chemical engineer develops a conceptual process flow diagram for a new reactor system that would use the TRL 1 catalyst to produce a specific polymer. They perform initial mass and energy balance calculations.
TRL 3	Experimental Proof of Concept	The catalyst is synthesized in a lab, and a small-scale, batch reactor is used to perform the reaction. The experiment confirms that the catalyst can indeed accelerate the reaction as predicted.
TRL 4	Technology Validated in Lab	A continuous-flow bench-scale reactor system is built. The system integrates the catalyst, pumps, and temperature controls. It is tested in a controlled lab environment to prove that the process can operate continuously and achieve the desired yield.
TRL 5	Technology Validated in a Relevant Environment	The reactor system is moved to a pilot plant. It is operated under conditions that simulate a full-scale industrial environment, including using non-ideal feedstocks and operating at different pressures and temperatures to assess its robustness.
TRL 6	Technology Demonstrated in a Relevant Environment	A larger, semi-works scale reactor is built within the pilot plant. It is operated for an extended period to produce a significant quantity of the polymer, demonstrating the technology's scalability and reliability in a realistic setting.
TRL 7	System Prototype Demonstration in an Operational Environment	The technology is integrated into a small, pre-commercial production line at an existing chemical plant. It produces a marketable quantity of the polymer, and the process is monitored to collect data on long-term performance and efficiency in an actual operational environment.
TRL 8	Actual System Completed and Qualified	The full-scale industrial plant is built, and the process is commissioned. It passes all safety and environmental regulations, and the product quality is certified. The plant is ready for commercial operation.
TRL 9	Actual System Proven in Operational Environment	The industrial plant has been operating successfully for a period of time, producing the polymer at the target rate and quality. The technology is considered fully proven and reliable for commercial use.

XII. TRL level example for Chemistry:

TRL Level		Description
TRL 1	Basic Principles Observed	A chemist synthesizes a novel polymer and publishes a paper on its fundamental properties, such as its unique molecular structure and reactivity.
TRL 2	Technology Concept Formulated	A material scientist, reviewing the TRL 1 research, proposes using the new polymer as a coating for biomedical implants to improve biocompatibility. They define the conceptual approach and perform theoretical simulations.
TRL 3	Experimental Proof of Concept	The polymer is synthesized in a lab and applied as a thin coating to a small metal coupon. The coupon is then placed in a simulated biological fluid to confirm that the polymer remains stable and does not degrade.
TRL 4	Technology Validated in Lab	The polymer coating is applied to a prototype of a biomedical implant. The coated implant is then tested in a lab to assess its mechanical integrity and adhesion under simulated physiological loads and conditions.
TRL 5	Technology Validated in a Relevant Environment	The coated implant is tested in a controlled animal model. The study aims to validate the coating's biocompatibility and stability in a living organism, a relevant biological environment.
TRL 6	Technology Demonstrated in Relevant Environment	A clinical-grade version of the coated implant is manufactured. A small pilot study is initiated to implant the device in a few human volunteers to demonstrate its safety and function in a living system.
TRL 7	System Prototype Demonstration in an Operational Environment	The implant enters a larger Phase II clinical trial. It is used in a broader patient population under the supervision of surgeons and clinicians, demonstrating its effectiveness and safety in its intended operational environment.
TRL 8	Actual System Completed and Qualified	The implant successfully completes Phase III clinical trials and receives approval from regulatory bodies (e.g., FDA). The manufacturing process for the coated implant is finalized and validated for mass production.
TRL 9	Actual System Proven in Operational Environment	The coated implant is commercially available and has been successfully used in thousands of patients, demonstrating a long-term track record of safety, efficacy, and performance in the real world.

XIII. TRL level example for Physics:

TRL Level		Description
TRL 1	Basic Principles Observed	A physicist observes and describes a new physical phenomenon, such as a new state of matter or a fundamental particle interaction. The results are published in a peer-reviewed journal.
TRL 2	Technology Concept Formulated	A research team proposes a conceptual design for a device that could exploit the newly discovered phenomenon from TRL 1, such as a new type of sensor or a quantum computer component.
TRL 3	Experimental Proof of Concept	A simple experiment is set up in a lab to demonstrate the feasibility of the concept. For instance, a small-scale prototype of the sensor is built and shown to react as predicted to the physical phenomenon.
TRL 4	Technology Validated in Lab	The core components of the device are integrated and tested together. The team verifies that the system works in a controlled lab environment and can reliably detect or manipulate the physical phenomenon.
TRL 5	Technology Validated in a Relevant Environment	The prototype is tested under conditions that mimic its final operating environment. For example, a new magnetometer is placed near a high-power electrical system to see if it is susceptible to electromagnetic interference.
TRL 6	Technology Demonstrated in Relevant Environment	A full-scale prototype is built and demonstrated in a relevant but not fully operational environment. An example would be a quantum processor prototype successfully executing a specific algorithm in a non-commercial setting.
TRL 7	System Prototype Demonstration in an Operational Environment	The device is integrated into a larger system and tested in its actual operational environment. For instance, a newly developed radiation detector is flown on a research satellite to measure cosmic rays.
TRL 8	Actual System Completed and Qualified	The device is finalized, passes all qualification and certification tests, and is ready for production. All design specifications are met, and the system is deemed ready for deployment.
TRL 9	Actual System Proven in Operational Environment	The device is fully deployed and has a proven track record of successful, reliable operation in its intended environment, such as the radiation detector successfully collecting data for a space mission.