Галицький економічний вісник https://doi.org/10.33108/galicianvisnyk_tntu
Galician economic journal, No 4 (101) 2026
https://doi.org/10.33108/galicianvisnyk_tntu2026.04
ISSN 2409-8892. Web: **http://galicianvisnyk.tntu.edu.ua**

UDC 330.341.1:005.334:658.589

MANAGING READINESS DESYNCHRONIZATION IN THE INNOVATION VALLEY OF DEATH: A TRL–IPRL–RISK FRAMEWORK FOR INDUSTRIAL COMMERCIALIZATION

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Summary. *The «valley of death» in industrial innovation has traditionally been understood as a funding gap between public research support and private capital. Commercialization practice, however, reveals a second and equally critical gap: the mismatch between technological maturation and the timely establishment of intellectual property (IP) protection, risk management, and funding preparedness. This study argues that effective innovation management requires the synchronization of technology readiness, intellectual property readiness, commercialization risks, and financing logic. Building on a critical review of readiness models, including Technology Readiness Level (TRL), Integration/System Readiness Levels (IRL/SRL), Demand Readiness Level (DRL), the KTH Innovation Readiness Level, and the Intellectual Property Readiness Level (IPRL), the article introduces readiness desynchronization as a distinct managerial phenomenon. It is defined as a systematic mismatch between the pace of technological maturation and the readiness of complementary IP, risk management, partnership, and funding mechanisms. To address this gap, the article proposes the TRL–IPRL–Risk Framework, a stage-specific diagnostic and decision-support tool that aligns TRL, IPRL, dominant commercialization risks, and appropriate funding instruments. The framework identifies four critical decision points (TRL 3 / IPRL 3, TRL 4 / IPRL 4, TRL 6 / IPRL 6, and TRL 8 / IPRL 8), each marking a qualitative shift in the dominant risk profile and requiring reconfiguration of IP strategy, disclosure control, partnership logic, and funding approach. The valley of death is thus conceptualized as a zone of intensified readiness desynchronization concentrated primarily between TRL 4 and TRL 8, where industrial projects face a dual gap: a financial readiness gap and an intellectual property readiness gap. The framework is deliberately positioned as a heuristic management tool rather than a rigid numerical index, recognizing the ordinal nature of readiness scales. It is operationalized through a five-step iterative algorithm and complemented by a readiness-buffer heuristic, which recommends preparing IP and risk-control measures in advance of critical transitions. The practical implications concern industrial developers, technology transfer offices, innovation managers, R&D units, and investors. The proposed framework improves the sequencing of managerial interventions, enhances protectability, supports investor due diligence, increases investment attractiveness, and reduces the likelihood that technologically promising projects stall in the pre-commercialization gap. Future research should focus on empirical validation, the development of diagnostic indicators, extension to early-stage creative search, analysis of capitalization gaps, and deeper exploration of funding alignment. In this way, the TRL–IPRL–Risk Framework can evolve into a broader program for managing desynchronization in industrial innovation.*

Key words: *innovation management, readiness desynchronization, valley of death, technology readiness level, intellectual property readiness level, commercialization risks, technology transfer, industrial innovation, intellectual asset management, TRL–IPRL–Risk Framework.*

Received 21.07.2026
Accepted 01.08.2026
https://doi.org/10.33108/galicianvisnyk_tntu2026.04.165 *Published 31.08.2026*

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УДК 330.341.1:005.334:658.589

УПРАВЛІННЯ ДЕСИНХРОНІЗАЦІЄЮ ГОТОВНОСТІ В «ДОЛИНІ СМЕРТІ» ІННОВАЦІЙ: TRL–IPRL–RISK FRAMEWORK ДЛЯ ПРОМИСЛОВОЇ КОМЕРЦІАЛІЗАЦІЇ

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Резюме. *«Долина смерті» у промислових інноваціях традиційно розглядається як фінансовий розрив між державною підтримкою досліджень і приватним капіталом. Водночас практика комерціалізації демонструє наявність другого, не менш критичного розриву: невідповідності між технологічним дозріванням і своєчасним формуванням механізмів охорони інтелектуальної власності, управління ризиками та фінансової готовності. Доведено, що ефективне управління інноваціями потребує синхронізації технологічної готовності, готовності інтелектуальної власності, ризиків комерціалізації та фінансової логіки. На основі критичного аналізу моделей готовності, зокрема Technology Readiness Level (TRL), Integration/System Readiness Levels (IRL/SRL), Demand Readiness Level (DRL), KTH Innovation Readiness Level та Intellectual Property Readiness Level (IPRL), запропоновано поняття десинхронізації готовності як окремого управлінського феномену. Його визначено як системну невідповідність між темпом технологічного дозрівання та готовністю комплементарних механізмів інтелектуальної власності, управління ризиками, партнерства й фінансування. Для подолання цього розриву запропоновано TRL–IPRL–Risk Framework, етапно орієнтований діагностичний інструмент підтримання управлінських рішень, який узгоджує TRL, IPRL, домінуючі ризики комерціалізації та відповідні інструменти фінансування. Модель визначає чотири критичні точки прийняття рішень (TRL 3 / IPRL 3, TRL 4 / IPRL 4, TRL 6 / IPRL 6, TRL 8 / IPRL 8), кожна з яких позначає якісну зміну домінуючого профілю ризику й потребує перегляду стратегії інтелектуальної власності, контролю розкриття інформації, партнерської логіки та фінансового підходу. «Долину смерті» концептуалізовано як зону посиленої десинхронізації готовності, зосереджену переважно між TRL 4 і TRL 8, де промислові проєкти стикаються з подвійним розривом фінансової готовності та готовності інтелектуальної власності. Запропонований фреймворк свідомо позиціонується як евристичний управлінський інструмент, а не як жорсткий числовий індекс, з урахуванням порядкової природи шкал готовності. Його операціоналізовано через п'ятиетапний ітеративний алгоритм та доповнено евристикою буфера готовності, яка рекомендує завчасно готувати заходи з охорони інтелектуальної власності та контролю ризиків перед критичними переходами. Практичне значення моделі стосується промислових розробників, офісів трансферу технологій, інноваційних менеджерів, R&D-підрозділів та інвесторів. Запропонований TRL–IPRL–Risk Framework покращує послідовність управлінських втручань, підвищує охороноздатність, підтримує due diligence інвестора, посилює інвестиційну привабливість і зменшує ймовірність того, що технологічно перспективні проєкти зупиняться в докомерційному розриві. Подальші дослідження мають бути спрямовані на емпіричну валідацію, розроблення діагностичних індикаторів, поширення підходу на ранні етапи творчого пошуку, аналіз розривів капіталізації та поглиблене дослідження узгодження фінансування. У такий спосіб TRL–IPRL–Risk Framework може розвинутися в ширшу програму управління десинхронізацією у промислових інноваціях.*

Ключові слова: *менеджмент інновацій, десинхронізація готовності, долина смерті інновацій, рівень технологічної готовності, готовність інтелектуальної власності, ризики комерціалізації, трансфер технологій, промислові інновації, управління нематеріальними активами, TRL–IPRL–Risk Framework.*

Дата надходження 21.07.2026
Дата прийняття 01.08.2026
https://doi.org/10.33108/galicianvisnyk_tntu2026.04.165 *Дата публікації 31.08.2026*

Problem statement. Industrial innovations frequently follow a persistent failure trajectory known as the innovation «valley of death», where promising technologies stall between research prototypes and commercially viable products. Conventional explanations emphasize a financing discontinuity between public research grants and later-stage private

investment. At the EU policy level, this phenomenon is framed as a «double valley of death», comprising both the pre-commercialization gap and the scaling gap [1].

However, evidence from prior studies and the practice of industrial technology commercialization indicates that capital scarcity alone does not fully account for these failures. The principal managerial challenge is the synchronization of four interdependent readiness dimensions: technological maturity, intellectual property readiness, dominant commercialization risks, and funding availability. The Technology Readiness Level (TRL) scale remains the standard for assessing technological maturity [2], while multidimensional readiness frameworks demonstrate that technological progress without concurrent readiness in market, business model, team, funding, and intellectual property domains does not necessarily lead to successful commercialization [3].

These readiness dimensions often progress at different rates. Technological advancement can substantially outstrip the formalization and strategic management of intellectual property, producing readiness desynchronization: projects that appear technologically mature but are inadequately prepared for investment, partnership, licensing, or market entry. For example, a technology may attain TRL 6, where a prototype is demonstrated in a relevant environment, while intellectual property measures remain limited to informal concept records. In such cases, the asset is poorly protected and unattractive to investors; the core impediment is therefore a mismatch between technological progress and complementary managerial preparedness.

Desynchronization is especially consequential for industrial innovations, which typically involve high capital intensity, long development cycles, complex supply chains, prototype testing, certification, and dependence on external partners. Managerial missteps at inappropriate stages amplify commercial risk: premature patent filings can yield overly narrow claims; delayed filings can permit imitation or disclosure; excessive secrecy can impede collaboration with industrial partners and investors; inadequate disclosure control during demonstrations can foreclose later protection. Each such error increases uncertainty and deepens the project's exposure to the innovation «valley of death».

The Ukrainian context accentuates these dynamics. Despite robust engineering schools, research institutions, and industrial competencies, many promising technologies fail to reach industrial implementation. Studies report declining technology transfer activity, weak innovation performance in industrial firms, deteriorating innovation capacity indicators, and insufficient integration of intellectual property mechanisms into commercialization processes [4, 5, 5, 6]. The full-scale war has exacerbated these problems by damaging infrastructure, displacing research and industrial teams, constraining resource access, and heightening demand for rapid deployment of defense-related and dual-use technologies [5].

Accordingly, industrial developers, technology transfer offices, innovation managers, and investors require a diagnostic managerial framework that links technological progress with intellectual property strategy, risk management, and funding roadmaps. Such a framework should not be a rigid numerical index, since readiness levels are ordinal and resist mechanical aggregation. Rather, it should function as a decision-support instrument for identifying critical desynchronization points where intellectual property readiness, risk mitigation, or funding preparation are insufficient for the next commercialization stage [7].

The concept of readiness desynchronization developed in this article generalizes the narrower notion of legal desynchronization introduced in the authors' companion legal study. Legal desynchronization describes the mismatch between technological maturation and timely legal or intellectual-property formalization. Readiness desynchronization extends this logic to the managerial level by incorporating not only intellectual-property preparedness but also dominant commercialization risks, funding alignment, and the sequencing of partnership decisions. In this way, the framework situates legal desynchronization as one dimension within a broader managerial phenomenon that determines whether industrial innovations can successfully transition from technical maturity to market readiness.

This article examines readiness desynchronization as a managerial manifestation of broader innovation desynchronization. It introduces the TRL–IPRL–Risk Framework, intended to align technology readiness, intellectual property readiness, dominant commercialization risks, and appropriate funding instruments to support managerial decision-making in industrial commercialization. Additional dimensions, such as the creative search stage, capitalization of intellectual activity results, and alignment of funding mechanisms with innovation maturity, are identified as priorities for subsequent research.

Analysis of Recent Research and Publications. The literature on innovation readiness, technology commercialization and the innovation *«valley of death»* can be grouped into several complementary research streams that together show commercialization failure rarely results from a single cause. The classical interpretation of the «valley of death» associates it with the transition gap between invention and innovation, where promising research results fail to attract sufficient resources for development, validation and market entry [9]. This interpretation remains important for industrial innovations, which typically require significant investment before stable revenues can be generated. However, the «valley of death» should not be understood solely as a financial gap; it also reflects technological, organizational, managerial, market and intellectual-asset management failures.

One research stream extends technological readiness logic beyond the maturity of an isolated technical solution. System-oriented studies introduced the transition from *Technology Readiness Level (TRL)* to *System Readiness Level (SRL)*, emphasizing that the maturity of individual components does not automatically imply the maturity of the whole system [10]. This is particularly relevant for industrial, defense and space technologies, where system integration, interface maturity and operational compatibility are critical for commercialization.

A second stream shifts attention from technology push to demand and market readiness. The *Demand Readiness Level (DRL)* concept demonstrates that advanced technical performance is insufficient when market pull, procurement logic or customer validation lag behind technological development [11]. Thus, commercialization failure may occur not because a technology is technically immature, but because the demand environment, customer acceptance and market entry conditions are not synchronized with the stage of technological development.

Managerial and failure-analysis studies provide another important perspective. Puzko systematizes key factors contributing to the innovation «valley of death», including insufficient market knowledge, excessive product complexity, weak teamwork, incorrect partner selection and premature scaling [11]. Sokur, analyzing startup risks, also emphasizes the importance of business preparedness and management capacity relative to purely research-and-development factors [12]. These findings support the argument that commercialization depends not only on technical refinement but also on the correct sequencing of managerial decisions concerning intellectual property, partnerships, disclosure, funding and scaling.

Multidimensional readiness frameworks offer a broader view of innovation maturity. Bruno et al. proposed extending TRL through social, organizational and legal readiness dimensions, thereby showing that technological maturity must be accompanied by broader institutional and regulatory preparedness [14]. This contribution confirms the need to assess non-technological readiness dimensions. At the same time, legal readiness in this approach has a broad regulatory meaning and is not identical to intellectual property readiness as a managerial dimension of commercialization.

The concept of *Intellectual Property Readiness Level (IPRL)* has been developed in Ukrainian research by Voitko, Pasichnyk and Yurchyshyn, who proposed a nine-level methodology for assessing the readiness of an intellectual property object for commercialization [15]. This approach is valuable because it adapts readiness logic to intellectual property management. However, it focuses mainly on the maturity of a specific intellectual property object and does not fully integrate IP readiness with technological maturity, dominant commercialization risks and funding decisions within a single stage-specific managerial framework.

Industry-oriented approaches to readiness assessment emphasize the importance of intellectual property intelligence in bridging the gap between technological maturity and commercial readiness. The *IP.com* white paper on readiness-level frameworks argues that assessment becomes more actionable when IP information supports stage-gate decisions, including patent landscape analysis**,** freedom-to-operate (FTO) analysis, and competitive positioning [16]. This perspective underscores that intellectual-property readiness should not be treated as a final legal formality, but rather as a managerial dimension of commercialization, integral to guiding decisions on protection, disclosure, partnerships, and investment.

Research on defense, dual-use and high-technology commercialization reinforces the need for institutional coordination, independent maturity verification, staged developer support and alignment with end-user requirements [17]. These factors are especially important where prototype testing, external validation, procurement rules and security considerations increase disclosure and imitation risks. Comparative institutional analysis of intellectual property in defense innovations also shows that international practice does not rely on a single universal model; different legal and managerial instruments are applied depending on the source of funding, technology readiness stage, security context and public interest [18].

Broader theories of innovation management provide the conceptual background for understanding commercialization as a systemic process. The national innovation systems approach explains innovation through interactions among firms, research institutions, government policy and knowledge infrastructure [19]. Freeman's historical analysis further shows that innovation capacity depends on institutional arrangements and the evolution of national systems of production, learning and technological change [20]. These approaches move the analysis beyond the individual firm and show that commercialization is embedded in a wider institutional environment.

The Triple Helix model develops this systemic view by emphasizing the interaction between universities, industry and government in the creation and commercialization of knowledge [21]. This is particularly relevant for industrial innovations originating in universities, research institutes or public-private partnerships. The open innovation paradigm further demonstrates that firms increasingly rely on both internal and external knowledge flows and therefore must manage intellectual assets strategically when cooperating with external partners [22]. However, open interaction also increases the importance of timely intellectual property protection, disclosure control and partner-related risk management.

Technology transfer studies stress the complexity of moving research results toward practical application. Bozeman shows that technology transfer is a multidimensional process involving institutions, actors, incentives, knowledge flows and policy environments [23]. Markman et al. emphasize the role of university-based technology transfer, licensing strategies, entrepreneurial mechanisms and organizational structures in commercializing research outcomes [24]. These studies explain the institutional and organizational context of commercialization but do not provide stage-specific decision rules for synchronizing technological maturity with intellectual property strategy, risk mitigation and funding instruments.

Thus, the existing literature provides several important but fragmented perspectives: the financial nature of the «valley of death», system and integration readiness, demand maturity, managerial causes of failure, multidimensional readiness assessment, intellectual property readiness, defense and dual-use commercialization, innovation systems, open innovation and technology transfer. However, a prescriptive managerial gap remains. Existing models can identify imbalances between readiness dimensions, but they do not sufficiently explain when and how managers should synchronize transitions in technological maturity with concrete actions concerning IP protection, disclosure control, risk prioritization and funding instruments.

This deficit is particularly acute for industrial innovations, where mistimed decisions can irreversibly reduce protectability, investment attractiveness and commercial potential. The

TRL–IPRL–Risk Framework proposed in this article aims to fill this gap by offering a diagnostic, stage-specific decision-support tool that aligns technology readiness, intellectual property readiness, dominant commercialization risks and appropriate funding instruments.

Purpose of the study. The preceding review confirms that the literature addresses individual dimensions of innovation readiness, including technological maturity, system integration, market demand, managerial competence, intellectual property protection and institutional context. However, these dimensions are typically examined separately or assessed in parallel. Consequently, the literature still lacks an integrated, stage-specific decision-support mechanism that synchronizes technological progress with intellectual property strategy, commercialization risks and funding logic in the process of industrial innovation commercialization.

Existing readiness frameworks, including *Technology Readiness Level (TRL)*, *Integration and System Readiness Levels (IRL/SRL)*, *Demand Readiness Level (DRL)*, multidimensional innovation readiness models and *Intellectual Property Readiness Level (IPRL)* approaches, are useful for diagnosing imbalances across different dimensions of innovation maturity. However, they fall short in explaining how specific transitions in technological maturity should inform concrete managerial decisions regarding intellectual property regimes, risk prioritization, disclosure control, partnership strategies, and funding instruments. This limitation is particularly consequential for industrial innovations, where mistimed actions such as premature patent filing, delayed formalization of secrecy, uncontrolled disclosure during prototype demonstration or misaligned funding searches can irreversibly reduce protectability, investment attractiveness and commercial potential.

A further unresolved aspect is the insufficient conceptualization of readiness desynchronization as a distinct managerial challenge. In this article, readiness desynchronization denotes a systematic mismatch between the pace of technological maturation and the preparedness of complementary managerial, intellectual property, risk and funding mechanisms. Unlike the traditional interpretation of the innovation «valley of death» as primarily a financial gap, this perspective emphasizes its broader structural character. For industrial innovations with long development cycles, complex supply chains, high capital intensity and dependence on external partners, such desynchronization may become a decisive barrier to commercialization.

This research aims to develop an integrated management model that synchronizes *Technology Readiness Level (TRL)*, *Intellectual Property Readiness Level (IPRL)*, dominant commercialization risks and appropriate funding instruments across the critical stages of industrial innovation commercialization.

The study addresses the following unresolved aspects of the general problem, translated into research objectives:

1. **Conceptualization.** Define readiness desynchronization as a managerial mismatch between technological maturation and complementary readiness dimensions, including intellectual property protection, risk management and funding alignment.
2. **Critical decision points.** Identify the stages at which qualitative shifts in dominant commercialization risk require reconfiguration of intellectual property strategy, disclosure control, partnership logic and funding approach.
3. **Framework development.** Design the *TRL–IPRL–Risk Framework* as a stage-specific diagnostic and decision-support tool that translates readiness assessment into structured managerial actions.
4. **Application algorithm.** Formulate a practical algorithm for applying the framework in industrial innovation projects by developers, technology transfer offices, innovation managers, R&D units and investors.

5. **Methodological positioning.** Treat the framework as a heuristic rather than a rigid metric, recognizing the ordinal nature of readiness scales and the risk of distorted aggregation [7]; focus on substantive gaps between readiness dimensions rather than mechanical numerical aggregation.

By addressing these objectives, the research contributes to innovation management by offering a practical tool for identifying and reducing readiness desynchronization in the commercialization of industrial innovations. The proposed approach is intended to support managerial decision-making in the innovation «valley of death» by aligning technological maturity, intellectual property readiness, risk mitigation and funding preparation within a coherent stage-specific logic.

Statement of the Task. The task of this article is to construct a stage-specific managerial model for identifying and reducing readiness desynchronization during the commercialization of industrial innovations. The study develops the *TRL–IPRL–Risk Framework* as an integrated diagnostic tool that connects four interdependent dimensions: *Technology Readiness Level (TRL)*, *Intellectual Property Readiness Level (IPRL)*, dominant commercialization risks and relevant funding instruments.

The proposed framework enables managers to assess whether an innovation project's intellectual property, risk management and funding preparedness correspond to its current stage of technological maturity. Particular attention is given to critical decision points at which a transition to a higher TRL alters the dominant risk profile and requires reconfiguration of intellectual property strategy, disclosure control, partnership logic and funding approach.

The framework translates readiness assessment into structured managerial actions. To support practical application, the article provides a synchronization matrix, identifies critical decision points in the industrial innovation lifecycle and formulates an application algorithm that can be used by industrial developers, technology transfer offices, innovation managers, R&D units and investors.

The model aims to improve the timing and sequencing of managerial interventions, thereby enhancing protectability, investment attractiveness and the commercial potential of industrial projects.

Statements of the main material of the study. This section presents the study's core conceptual and practical contributions: the concept of readiness desynchronization, the *TRL–IPRL–Risk Framework* with its synchronization matrix, four critical decision points and a practical application algorithm for managers, technology transfer offices and investors.

Concept of readiness desynchronization. Industrial innovation projects rarely fail for a single isolated reason. The persistence of the innovation «valley of death» reflects recurring misalignment among the key dimensions of project development. To capture this pattern, the study introduces readiness desynchronization.

Readiness desynchronization is a systematic mismatch between the pace of technological maturation and the readiness of complementary managerial, intellectual property, risk-related and financial mechanisms required for successful commercialization. The mismatch occurs when one readiness dimension advances substantially ahead of, or falls substantially behind, the others. As a result, a project may appear mature in one respect yet remain commercially vulnerable overall.

This concept shifts attention from a narrow financial interpretation of the valley of death to the timing and sequencing of managerial decisions. For example, a project may secure funding but fail because IP protection was not established prior to external disclosure. Conversely, a project may hold formal IP documentation but lack adequate risk management, partner agreements, freedom-to-operate (FTO) analysis or a funding strategy for the next stage. In both cases the core problem is temporal misalignment among interdependent readiness dimensions.

The typical forms of readiness desynchronization are summarized in Table 1.

Table 1. Forms of Readiness Desynchronization in Industrial Innovation Projects

Type of desynchronization	*Description*	*Managerial consequence*
Premature patenting	Patent filing before the technical solution is sufficiently defined	Narrow claims; weak coverage of subsequent improvements; additional filing costs
Delayed formalization	Prototype development while IP remains limited to informal records	Weak asset protection; higher investor risk perception; reduced valuation
Unmanaged disclosure	Presentation to partners without confidentiality arrangements	Loss of novelty; reduced patentability; weakened bargaining position
Funding mismatch	Seeking venture capital too early or relying on grants when scale-up capital is required	Failed funding rounds; delayed timelines; missed market opportunities
Inadequate risk monitoring	Failure to update the risk profile as the technology matures	Late identification of obstacles; reactive management

Source: authors' development.

Each form in Table 1 reflects a sequencing failure: actions taken too early, too late or in the wrong order deepen the valley of death by leaving technically promising projects legally, commercially or financially unprepared for the next stage.

TRL–IPRL–Risk Framework. To address readiness desynchronization, the study proposes the *TRL–IPRL–Risk Framework* as a stage-specific diagnostic and decision-support tool. The framework couples four interdependent blocks: *Technology Readiness Level (TRL)*, *Intellectual Property Readiness Level (IPRL)*, the dominant commercialization risk at each stage and the appropriate combination of IP and funding instruments. The structural blocks are shown in Table 2.

Table 2. Structural Blocks of the TRL–IPRL–Risk Framework

Framework block	*Description*	*Managerial question*
TRL	Maturity of the technical solution from concept to operational deployment	What is the current technological maturity?
IPRL	Status of IP identification, documentation, protection and strategic management	Is the intellectual asset sufficiently protected for commercial use?
Risk	Dominant commercialization risk at the current stage	What is the main threat to transition to the next stage?
IP & funding instruments	Appropriate IP instruments, managerial actions and funding sources	What should be done now and what funding is appropriate?

Source: authors' development.

Its principal contribution is dynamic coupling: each TRL stage is associated with a target IPRL, a dominant risk category and a recommended managerial response. Unlike models that only diagnose imbalances, this framework translates diagnosis into intervention by linking identified gaps to concrete actions. The framework deliberately avoids arithmetic aggregation of ordinal readiness scores, in line with the methodological critique of readiness-level aggregation [7]. It functions as a heuristic to reveal substantive gaps rather than as a numerical index.

The IPRL audit may be based on the nine-level methodology proposed by Voitko, Pasichnyk and Yurchyshyn [15]. In the proposed framework, this audit is adapted to the project level and covers patent status, know-how documentation, confidentiality arrangements, trade-secret formalization, freedom-to-operate (FTO) analysis and trademark preparation. The framework's logic is consistent with multidimensional readiness approaches such as the KTH Innovation Readiness Level model [3].

Synchronization matrix. The *TRL–IPRL–Risk Framework* synchronization matrix maps TRL stages to target *IPRL* levels, dominant risks, management actions and suitable funding instruments. The full mapping is presented in Table 3.

Table 3. TRL–IPRL–Risk Framework Synchronization Matrix

TRL stage	*Target IPRL*	*Dominant risk*	*Management action*	*Funding instrument*
TRL 1–2	IPRL 1–2	Scientific uncertainty; authorship ambiguity	Fixation of idea; laboratory records; preliminary IP identification; patent information search	University or public research support
TRL 3	IPRL 3	Patentability risk; protection uncertainty	Decide between patenting and know-how; novelty search; preliminary patentability assessment	Early-stage grants; proof-of-concept support
TRL 4	IPRL 4	Loss of priority; copying risk	File a patent application or formalize a trade secret regime; access control; preliminary FTO analysis	Applied research grants; seed funding; business angels
TRL 5	IPRL 5	Disclosure risk during validation	Use non-disclosure agreements (NDAs); create internal know-how register; controlled access protocols; update IP strategy	Seed funding; early industrial partners
TRL 6	IPRL 6	Technology leakage during prototype demonstration	Control diffusion; expand patent protection; prepare IP valuation and due diligence materials	Venture investment; corporate venture capital; strategic investment
TRL 7	IPRL 7	Mismatch between market, manufacturing and partnership logic	Prepare licensing strategy; structure technology transfer agreements; negotiate industrial partnerships	Strategic partners; corporate investment; project finance
TRL 8	IPRL 8	Weak commercial identification; scaling risk	Register trademarks; finalize licensing and production agreements; secure contractual control over partners and supply chains	Scale-up capital; accelerators; growth investors
TRL 9	IPRL 9	Competitive pressure; erosion of market position	Manage IP portfolio; monitor infringement; administer licenses; reinvest returns	Revenue reinvestment; portfolio financing

Source: authors' development.

Identification of the Innovation «Valley of Death» within the Framework. Within the proposed *TRL–IPRL–Risk Framework,* the innovation «valley of death» is not treated as a single threshold in the lifecycle. It is conceptualized as a zone of intensified readiness desynchronization in which technological maturation begins to demand substantially higher levels of intellectual property preparedness, risk control, partnership structuring and funding readiness. In this logic, the TRL 3 / IPRL 3 point precedes the core valley of death interval and should be understood as a pre-valley decision gate. At this stage, the central managerial issue is the choice of protection regime, whether to pursue patent protection or retain the solution as know-how. This decision is critical because it may either prevent or create the preconditions for later commercialization failure. The valley of death as a zone of intensified commercial risk, characterized by capital constraints, disclosure vulnerabilities, external validation requirements and heightened investor scrutiny, does not fully emerge until TRL 4. At that point the technology moves beyond initial proof of concept and begins to require substantial external resources for validation, demonstration, partnership negotiations and preparation for scale-up. Therefore, for industrial innovations the core valley of death zone is concentrated primarily between TRL 4 and TRL 8, while TRL 3 / IPRL 3 functions as the critical entry gate that determines whether the project enters this zone with sufficient intellectual property preparedness.

At TRL 4, projects typically move from conceptual and laboratory validation toward a defined technical solution. At this stage, the risks of loss of priority, copying and uncontrolled disclosure become acute. At TRL 5–6, technologies enter validation and prototype demonstration in relevant environments, which heightens the need for freedom-to-operate (FTO) analysis, confidentiality arrangements, due-diligence documentation and IP valuation. At TRL 7–8, projects

approach industrial demonstration, production preparation, market identification and scaling. Here, investors and industrial partners require evidence not only of technological feasibility but also of protectability, contractual control and commercial readiness.

This localization aligns with the logic of European innovation funding instruments. The EIC Transition instrument supports projects progressing from early proof of concept toward higher readiness, including validation and demonstration in application-relevant environments [25]. The EIC Accelerator, in turn, targets high-risk innovations at later readiness stages, particularly TRL 6 to TRL 8, combining grant support with investment instruments to enable development, market deployment and preparation for scale-up [26].

The financial-readiness gap arises when public research or proof-of-concept funding becomes insufficient, while private, corporate or blended finance requires evidence of validation, scalability and investment readiness. The intellectual-property readiness gap arises when technological progress is not accompanied by timely patentability assessment, know-how documentation, trade-secret formalization, disclosure control, freedom-to-operate (FTO) analysis and preparation of licensing or production agreements. Thus, a project may enter the valley of death not only because it lacks capital, but also because it reaches a technologically visible and investment-sensitive stage without sufficient IP and risk-management preparedness.

In this sense, the most vulnerable interval of the framework is TRL 4–8, with particularly critical transitions at TRL 4 / IPRL 4, TRL 6 / IPRL 6 and TRL 8 / IPRL 8. These stages explain why the valley of death is operationalized here through critical decision points rather than a single threshold. The model therefore identifies the valley of death as a zone where readiness desynchronization becomes commercially dangerous and requires proactive managerial intervention.

Table 3 links each technological stage with a target IP readiness level, a dominant risk and an appropriate set of managerial and funding instruments, enabling identification of desynchronization as a timing and sequencing failure.

The synchronization matrix can also be represented as a stage-based decision logic in which critical points emerge at the moments when the dominant risk changes and the previous IP or funding strategy becomes insufficient. This logic is visualized in Figure 1.

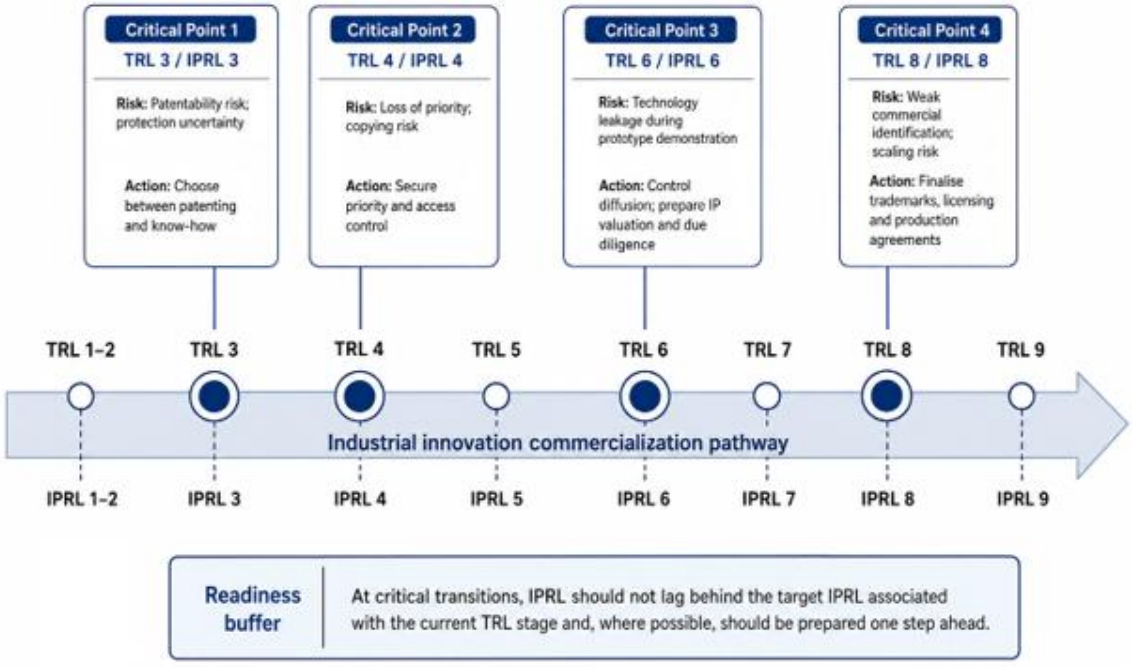


Figure 1. Critical Decision Points and Readiness Buffer in the TRL–IPRL–Risk Framework

Source: authors' development.

Critical decision points. From the synchronization matrix, four critical decision points emerge where the dominant risk changes qualitatively and managerial strategy must be reconfigured (Table 3):

- ***TRL 3 / IPRL 3: patent versus know-how***. Decide whether to pursue patent protection or retain secrecy, based on reverse-engineering risk, codifiability and the need to demonstrate the solution. A wrong decision may narrow future protection or cause loss of protectability through uncontrolled disclosure.
- ***TRL 4 / IPRL 4: securing priority and access control***. Move from conceptual assessment to securing priority: file a patent application or formalize a trade secret regime, implement access restrictions and conduct preliminary freedom-to-operate (FTO) analysis. Ignoring FTO risks may later undermine investor confidence or create infringement costs.
- ***TRL 6 / IPRL 6: controlling diffusion during prototype demonstration***. Implement disclosure protocols, prepare IP valuation and due diligence materials, and manage investor and partner access. This stage is sensitive because external observers may directly see the technology.
- ***TRL 8 / IPRL 8: commercial identification and scaling***. Finalize trademarks, licensing and production agreements, and secure contractual control over partners and supply chains. The focus shifts from technical feasibility to market identification and scalable delivery.

Before crossing each critical point, managers should create a readiness buffer by preparing the relevant IP and risk control measures in advance. Where feasible, IPRL should not lag behind the target IPRL associated with the current TRL stage and should preferably be prepared one step ahead. The buffer is a practical safety margin rather than a rigid numerical rule.

Application algorithm. The framework is operationalized through a five-step, iterative algorithm summarized in Table 4.

Table 4. Application Algorithm of the TRL–IPRL–Risk Framework

Step	*Action*	*Output*
1	Assess current TRL using an accepted technology-readiness methodology	Current TRL level
2	Identify dominant commercialization risk using the synchronization matrix (Table 3)	Dominant risk category
3	Conduct a rapid IPRL audit using the nine-level methodology [15]	Current IPRL level
4	Compare current IPRL with target IPRL for the TRL stage and diagnose any readiness desynchronization gap	Gap diagnosis
5	Implement recommended managerial action from the synchronization matrix and reassess the project	Updated readiness profile

Source: authors' development.

Note: The IPRL audit covers patent status, know-how documentation, non-disclosure agreements (NDAs), trade-secret formalization, freedom-to-operate (FTO) analysis and trademark preparation.

The algorithm is iterative: after each managerial action, the readiness profile should be reassessed. Transitions are safer when IP readiness, risk mitigation and funding preparation correspond to the expected increase in technological maturity.

Managerial implications. The framework provides four practical benefits. First, TRL and IPRL establish a shared vocabulary for engineers, legal counsel and finance teams. Second, early identification of dominant risks enables pre-emptive allocation of managerial attention and resources. Third, linking technical milestones to intellectual property protection, risk control and a realistic funding roadmap supports due diligence and increases transparency for investors. Fourth, avoiding premature patent expenses, delayed confidentiality measures and misdirected funding requests reduces waste and improves the timing of managerial interventions.

Conclusions. The research shows that the industrial innovation «valley of death» cannot be reduced to a simple financing gap between public research support and private investment. In industrial commercialization, the phenomenon also reflects a managerial problem: the desynchronization of interdependent readiness dimensions that must evolve in a coordinated manner for successful market transition. Technological maturity, intellectual-property readiness, dominant commercialization risks and funding preparedness often develop at different speeds. When such mismatches are not detected and corrected in time, even technically promising projects may lose protectability, investment attractiveness and commercial potential.

The study delivers three linked contributions.

Conceptual contribution. The article introduces and operationalizes *readiness desynchronization* as a distinct managerial phenomenon: a systematic mismatch between the pace of technological maturation and the readiness of complementary intellectual-property, risk-management and funding mechanisms. This reframes the valley of death from a primarily financial problem into a timing and sequencing problem: when to protect, when to disclose, when to involve partners, when to seek specific sources of capital and when to reconfigure the commercialization strategy. The typology of desynchronization, including premature patenting, delayed formalization, unmanaged disclosure, funding mismatch and inadequate risk monitoring, provides a diagnostic vocabulary for recurring failure patterns in industrial projects.

Methodological contribution. The *TRL–IPRL–Risk Framework* is proposed as a stage-specific diagnostic and decision-support tool that synchronizes Technology Readiness Level, Intellectual Property Readiness Level, dominant commercialization risks and relevant funding instruments. Its principal feature is dynamic coupling: each TRL stage is linked to a target IPRL, a dominant risk category and a corresponding set of managerial and funding responses. The framework translates multidimensional diagnosis into structured managerial intervention while remaining a heuristic rather than a rigid numerical index, recognizing the ordinal nature of readiness scales and the risk of distorted aggregation [7].

Practical contribution. The study identifies four critical decision points in the industrial lifecycle: TRL 3 / IPRL 3, TRL 4 / IPRL 4, TRL 6 / IPRL 6 and TRL 8 / IPRL 8 (see Fig. 1), where the dominant risk profile changes qualitatively and IP, disclosure, partnership and funding strategies must be reconfigured. The synchronization matrix and the five-step application algorithm provide actionable guidance for developers, technology transfer offices, innovation managers, R&D units and investors. The readiness-buffer heuristic recommends preparing IP and risk-control measures in advance of critical transitions to reduce sequencing failures.

The framework complements existing readiness approaches. The IPRL audit can be grounded in the nine-level methodology by Voitko, Pasichnyk and Yurchyshyn [15], and the framework's multidimensional logic aligns with the KTH Innovation Readiness Level model [3]. It therefore integrates and extends current tools rather than replacing them.

For industrial innovation projects, the implications are concrete. Synchronizing readiness dimensions:

- reduces the likelihood of costly sequencing failures;
- improves communication between technical, legal and financial actors;
- supports investor due diligence by linking technical milestones to intellectual-property and funding logic;
- strengthens the innovation's commercial position before disclosure, demonstration or scaling.

Overcoming the innovation «valley of death» thus requires not only additional funding but coordinated management of readiness transitions.

Prospects for further research. Further work should develop and validate the proposed approach along several lines.

1. *Empirical validation***.** Test the TRL–IPRL–Risk Framework on real industrial projects, prioritizing defense, dual-use and high-technology sectors where disclosure, security and IP risks are acute.

2. *Diagnostic indicators***.** Develop diagnostic indicators that measure the degree of readiness desynchronization without reducing the framework to a rigid mathematical index.

3. *Early-stage extension***.** Extend the concept to earlier stages of creative search, where the transition from idea to protectable technical solution requires distinct managerial analysis.

4. *Capitalization gap***.** Examine desynchronization between intellectual activity and its capitalization as intangible assets, including valuation and accounting implications.

5. *Funding alignment***.** Analyze in greater detail the alignment between TRL, IPRL, risk profile and appropriate sources of capital, including public grants, early-stage grants, proof-of-concept support, seed funding, corporate venture capital and scale-up capital.

By pursuing these directions, subsequent studies can embed the TRL–IPRL–Risk Framework within a broader research program that links creative search, IP protection, capitalization and funding into a coherent model of industrial innovation management.

The *TRL–IPRL–Risk Framework* is intended as a practical, stage-specific tool for managers and investors. Its value lies in early detection of readiness desynchronization and in guiding timely, proportionate managerial responses that preserve protectability, attract investment and increase the likelihood of successful commercialization in industrial contexts.

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