TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue III, September, 2024

METHODOLOGY FOR AN AGGREGATE READINESS LEVEL ASSESSMENT OF INNOVATIVE TECHNOLOGIES

Laura-Florentina BOANȚĂ, Alexandru MARIN, Miron ZAPCIU, Bogdan-George RÂNEA

Abstract: *This paper introduces a new approach for assessing the "aggregate" readiness level (AgRL) of an innovative material, specifically a novel asphalt concrete made from recycled glass and plastic waste. The proposed approach builds on the existing framework of Technology Readiness Level (TRL) by integrating additional readiness dimensions: Market Readiness Level (MRL), Regulatory Readiness Level (RRL), Acceptance Readiness Level (ARL), Organizational Readiness Level (ORL), and Commercial Readiness Index (CRI). These dimensions are considered in conjunction to evaluate their interdependent impacts, establishing a comprehensive metric for determining the overall maturity of emerging technologies. This framework serves as a foundational tool for research organizations to gauge the readiness of new technologies, particularly in the context of pilot projects seeking public or private investment.*

Key words: *Aggregate Readiness Level, Technology, Market, Regulatory, Acceptance, Organizational.*

1. INTRODUCTION

1.1.“Readiness” and “maturity”

When businesses plan to adopt a new technology, assessing their preparedness for implementation is essential. "Readiness" refers to the appropriateness of a technology or product for integration within a larger system in a specific setting. The terms "Readiness" and "Maturity" are frequently used as synonyms, implying that a product with greater maturity is likely to demonstrate a higher degree of preparedness for a particular application or system than a product with lower maturity [1].
The different factors that influence readiness, along with their effects on the system or product, complicate the evaluation of the technology's overall readiness and the comprehensive risk assessment.

1.2.Commercial indicators

Commercial indicators are utilized to evaluate how effectively a company can leverage emerging technologies. These indicators are separate parameters that are consolidated into a single Commercial Readiness Index (CRI) [2]. The CRI framework assists in identifying key performance indicators (KPIs) within a specific case study's manufacturing process. Additionally, it aids experts in understanding and exploring the commercialization potential of a complex product by pinpointing the primary obstacles that must be overcome to transition from the present condition to the intended future condition. The technology framework addresses the technological uncertainties of the product and highlights the project and process risks related to its manufacturing.

2. PROBLEM FORMULATION

2.1 Multi-dimensional assessment

To fully grasp the nuances of technology development and deployment, this paper asserts that it is crucial to conduct a multi-faceted evaluation of technology readiness. It is important to consider various aspects: the level of technological advancement, market preparedness, legal considerations, societal

Received: 30.07.24; **Similarities**: 19.08.24: **Reviewed**: 31.07./31.07.24: **Accepted**:06.09.24.

acceptance, and integration challenges for end users. These are crucial questions that need to be addressed in a balanced approach to readiness. The conventional method for evaluating readiness typically follows a sequential process, starting with idea generation, moving through the development of individual components, followed by an integrated prototype, and culminating in the final product. Given the varied pathways products may take from conception to market, relying on a singular, unified scale that covers all aspects is not feasible. Consequently, based on our review of the literature and subsequent analysis, we propose a framework for readiness assessment encompassing six dimensions [3]. These dimensions are: i) Technology Readiness Level (TRL), ii) Market Readiness Level (MRL), iii) Regulatory Readiness Level (RRL), iv) Acceptance Readiness Level (ARL), v) Organizational Readiness Level (ORL), and vi) Commercial Readiness Index (CRI). By integrating these six dimensions of readiness assessment, a balanced approach provides a comprehensive six-dimensional description of a technologies and commercial's preparedness. This holistic assessment enables us to identify potential barriers and areas that require the attention of technology developers throughout the product's development process. Building upon the previous literature focusing on readiness assessments, our method incorporates a 9-point scale across the first five dimensions, and a 6-point scale across Commercial Readiness Index (CRI), resulting in multiple scales. Each readiness metric features a numerical value, a detailed explanation of what each value signifies, and the practical implications associated with each level.

3. READINESS LEVELS

3.1. TRL

The Technological Readiness Level (TRL) serves as a measure to assess the progress and developmental stage of a technology. The TRL framework consists of several levels, each representing a specific stage of technological advancement. Starting at TRL 1, where basic principles are observed and reported, it progresses through stages of concept formulation, critical function validation, component validation, and prototype demonstration in relevant environments. At higher TRL levels, there are demonstrations of system prototypes, completion and qualification of the actual system, and proven success through mission operation. The TRL framework provides a standardized approach to assess and communicate the readiness of technology for real-world implementation.

3.2. MRL

Market Readiness Level (MRL) aims to adapt and commercialize technology for the market. However, there is a lack of consensus on how to approach this challenge. MRL, similarly with TRL, consists of distinct stages that include initial market intuition, formulating product descriptions and target markets, identifying market needs and product features, validating the market through pilot campaigns, clarifying the business model, launching to small customer groups, confirming customer satisfaction and progress, achieving stable sales volume, and reflecting a stable or growing market. These stages help evaluate technology readiness and guide decisions for successful market entry.

3.3. RRL

Regulatory Readiness Level (RRL) is a concept that relates to the process of legalizing a product, ensuring compliance, and facilitating market entry. Navigating the regulatory landscape involves progressing through different levels of readiness. At Level 1, the legal aspects of a new product are uncertain, presenting challenges. Advancement to Level 2 may require changes in existing laws to accommodate the product's requirements. Level 3 involves modifications or reinterpretation of regulations. Level 4 necessitates obtaining difficult-to-acquire certificates or approvals. As the process continues, Level 5 signifies easier access to necessary certificates and approvals. Level 6 indicates a higher likelihood of obtaining approvals. Approaching Level 7, mandatory approvals become imminent and essential for market entry. Level 8 signifies alignment with

general regulatory conditions. Finally, Level 9 represents full approval for both product use and production. The RRL framework provides guidance to organizations, ensuring they meet the necessary regulatory requirements for successful market entry.

3.4. ARL

Acceptance Readiness Level (ARL) focuses on establishing social acceptance and legitimacy for new products or technologies.

The framework consists of several levels that indicate the degree of acceptance. Starting from Level 1, where the technology is perceived as illegitimate, it progresses through levels of controversy, rejection, scepticism, and perceived inappropriateness. At higher levels, the technology faces questioning, becomes questionable, and may be unwanted by specific interest groups. Goal is to reach Level 9, where the technology enjoys widespread acceptance without any doubts.

The ARL framework provides valuable insights to organizations, helping them understand and overcome challenges to achieve broad acceptance and legitimacy.

3.5. ORL

The Organizational Readiness Level (ORL) assesses how well technology integrates into current systems and its alignment with established technologies. The ORL framework consists of several levels that assess the readiness of an organization for technology adoption.

Starting at Level 1, where the technology significantly diverges from existing practices, it progresses through levels of openness, idea formulation, and explicit descriptions of integration or replacement processes. At advanced levels, detailed strategies for integration are developed, including potential organizational adjustments and modifications or replacements of current processes or technologies. U

ltimately, Level 9 signifies the complete and smooth integration of the new technology in relation to current systems or workflows. The ORL structure provides organizations with a structured approach to evaluate and ensure their readiness for technology implementation.

3.6 CRI

The Australian Renewable Energy Agency (ARENA) has established the Commercial Readiness Index (CRI) framework to work alongside Technology Readiness Levels (TRLs) by evaluating the commercial advancement of technologies through six distinct indicators. While TRLs serve as a standard for monitoring the advancement and development of technologies along the innovation continuum, the CRI aims to assess the commercial standing of a project.

The CRI evaluation begins when there is evidence that the technology is feasible in the field, which corresponds to TRL 2.

The CRI assessment extends until the technology achieves the stage of commercial deployment. According to ARENA, enhancing the commercial readiness of a technology necessitates advancement along specific commercial indicators.

To evaluate the attractiveness of new technologies, companies can examine their technical and financial feasibility, market prospects and potential for benefit realization. Organizational support, market expertise, and integration within the organization are factors that can accelerate the commercialization process.

The terms "maturity" and "readiness" are closely related and frequently used interchangeably. In evaluating the process of bringing technologies to market within their sector, ARENA has identified metrics through stakeholder consultations, literature reviews, and practical experience.

The literature highlights that commercial readiness indicators should encompass stakeholders' involvement, technical feasibility, market potential and expertise, financial viability and benefit realization, organizational backing, and robust R&D efforts [4]. In this context, the metrics include: Regulatory Framework, Stakeholder Endorsement, Technical Efficiency, Financial Performance -

Costs, Financial Model - Revenue, Market Potential, Industry Supply Chain and Capabilities, and Organizational Maturity. Each metric can be assigned a maturity stage from 1 to 6, where Level 1 represents the lowest maturity and Level 6 signifies the highest level of development for that specific metric.

4. AGGREGATED READINESS LEVEL

The assessment of readiness levels is typically conducted by selecting a specific metric that suits the needs of a particular stakeholder for a partial analysis.
The product is then evaluated against this chosen metric. For example, functionality can be used to gauge the technical merit of a product, economic viability may be assessed to determine commercial potential, or readiness for standardization might be evaluated independently. In this context, we introduce a methodology crafted for both comprehensive and thorough evaluation.
This approach integrates various readiness stages into a multi-dimensional readiness estimator, offering a comprehensive perspective. Our work in axiomatic design supports the representation of product assessment as an Aggregated Readiness Level (AgRL), with the ability to also display individual index scores.
The Aggregated Readiness Level (AgRL) method provides significant advantages for product development and success.
Attaining the highest level of readiness across all sub-metrics categories a product for optimal success in its target market.
However, if certain sub-metrics score lower, they become limiting factors that can restrict the product's overall success.
To overcome this, the AgRL method emphasizes a shift in the product design objective towards holistic optimization rather than focusing solely on individual design aspects.
This comprehensive approach maximizes overall readiness and, consequently, enhances overall success. Furthermore, the AgRL method directs design trade-offs and decisions by evaluating their expected effects on overall preparedness and product effectiveness.
By using this principle as a valuable reference point during the product design process, informed choices can be made, ensuring that decisions align with the goal of achieving maximum readiness. In summary, the AgRL method optimizes the product, addresses limiting factors, and guides design decisions to maximize overall readiness and success in the target market.

4.1. Case study

As the case study we take an innovative product, i.e. an asphalt mixture type material for a unique base and connecting road layer, characterized by the fact that, in addition to conventional mineral aggregates (rock and filler aggregates), it simultaneously includes particles in exclusively granulated form from waste derived from glass and plastic materials, regardless of the resin code identified.
The process for obtaining this material is characterized by the fact that the glass is mixed with the aggregates and the filler at 160-180°C, the bitumen heated to 180°C is added and, after kneading the mixture for 30-35 sec., we add the fine plastic component and continue kneading for another 10-15 seconds, resulting in a polymerized asphalt mixture.
This product and its corresponding manufacturing process was subject of patent filing, code RO135744A0.
In this simple case study, an assessment was made for this asphalt mixture, with the six sub-metrics presented before.
The responses to a dedicated questionnaire are presented (in yellow mark) in Table 1, producing scores for each dimension of analyse, which were plotted on two spider diagrams (fig. 1).
According to the literature [3], we associate the AgRL method with a Multi-Index Analysis (MIA). The radar chart illustrates each metric on a spectrum from MIA 1 to 15, with a goal score of MIA 14 for every sub-metric (right spider). The subtle sector boundaries and positions demonstrate how the separate sub-metrics correspond to MIA values as outlined in Table 2. From Table 2, it is evident that for diverse values in Table 1, the corresponding CRI value consistently remains at 1. This diagram effectively displays both the scores of individual sub-metrics and, visually through the area, the overall holistic MIA status of the product. In this

case, the product achieves a MIA rating of 5, constrained by the smallest sub-metric score (TRL).

Table 1

Questionnaire for evaluating the maturity of a product on five representative dimensions (authors own ellaboration)

Q. no.	TRL	MRL	RRL	ARL	ORL	If yes the level is
1	Is the product fully developed and prepared for market release?	Is the product widely available on the market with an established business model?	Does the use and production of the product pose regulatory challenges?	Is the application of the product fully compliant and acceptable from both a political and socio-economic perspective?	Can the product work seamlessly with other available products?	9
2	Extensively examined and verified?	Is the market demand for the product maintaining stability or experiencing growth?	Does the production and utilization of the product comply with standard regulatory guidelines?	Is the application of the product regarded as problematic, in the context of unfair competition at national and international level?	Is the use of the product aligned with existing work processes and any specialized technologies needed?	8
3	Has the product been assessed and confirmed in real-world conditions?	Is the market requirement for the product fully confirmed ?	Are the necessary approvals/permissions close to being granted?	Is the use of the product seen as lacking "political support" at the local/regional/national level?	Are only minor organizational changes required to use the product?	7
4	Has the prototype been evaluated and confirmed in the appropriate environment?	Was the product introduced in limited quantities to gauge market response?	Is it probable that the required approvals or permissions will be granted?	Is the use of the product seen as " bothering " certain socio-economic interest groups?	Will significant organizational changes be required for the product to be implemented effectively?	6
5	Have the main components been tested together and validated in a lab or simulated environment?	Has a business model been developed ?	Will using the product necessitate readily obtainable permissions or approvals?	Does the use of the product seen as economically unsustainable among certain interest groups?	Is there a plan to integrate the product with current business processes?	5
6	Are the main components of the product tested and validated separately ?	The market requirement and product specification are confirmed by potential customers ?	Will using the product require difficult permissions/approvals?	Is the use of the product seen as polluting among certain socio-economic groups?	Have the current functional processes been outlined?	4
7	Has the product concept been thoroughly presented and detailed?	Are the industry / market requirements and product	Will the application of the product demand changes in regulations?	Is the use of the product seen as very expensive among certain socio-economic groups?	Has an idea been formulated regarding the integration and adaptation of the	3

		specifications well-defined?			**product to the current functional processes ?**	
8	**Is the idea of the product fully described?**	**Have the market requirement and possible technical solutions been identified ?**	**Will using the product require legal regulatory changes?**	**Is the use of the product controversial, due to ignorance, among some socio-economic categories?**	**Is product integration with current business processes ambiguous or troubling?**	**2**
9	**Has the product concept been developed?**	**Market requirement clarified ?**	**Are the lawful and compliance aspects of the product ambiguous or uncertain?**	**Will the application of the product be considered unacceptable in terms of socio-economic impact?**	**Will the use of the product represent a fundamental change in the current operational processes?**	**1**

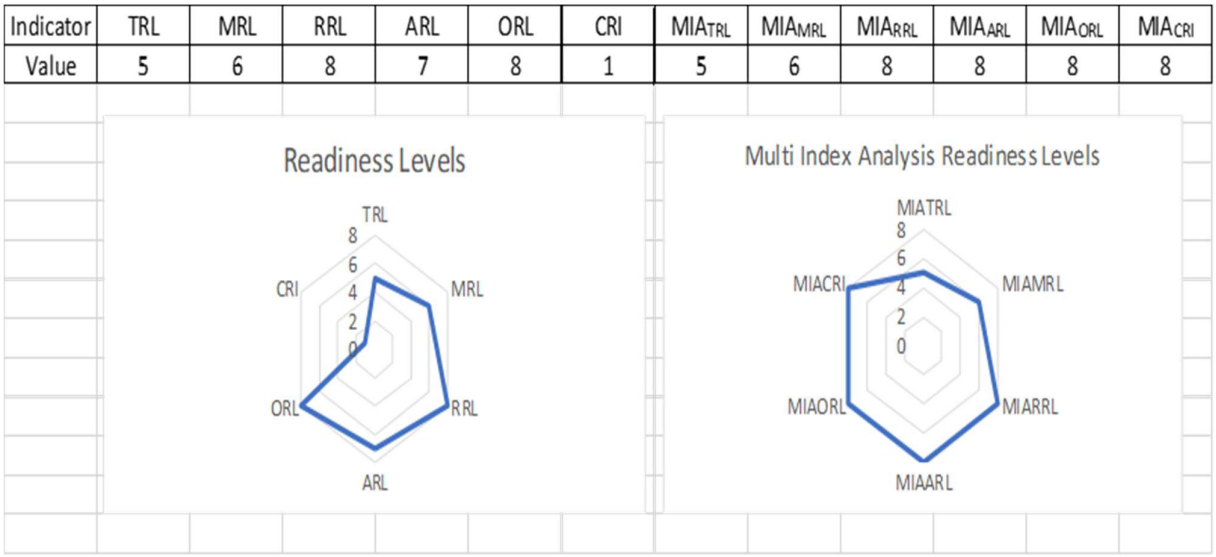

Fig. 1. Spiders (left – Readiness Levels, right – Multi Index Analysis Readiness Levels) – authors own elaboration.

This is just the simplest interpretation, considering that the lowest value, so to say, "the weakest link", settles the actual maturity level of the innovative technology, from this point over being necessary to make developments to get closer to the market with all dimensions of analyse tending to reach their maximal possible values.

This combined analyse emphasize that reaching clients with innovative products is not only a matter of technology maturity (TRL), but also considering other dimensions of evaluation, such as MRL, RRL, ARL, ORL and maybe even others, e.g., Manufacturing Readiness Level (MRL), Systems Readiness Level (SRL) etc., literature being generous in this respect.

Passing from MIA to AgRL is just a formal aspect of the problem under study, necessary adaptions being easy to introduce, when understanding the essence of the improved method of evaluating the maturity and readiness criteria for going to market with innovative products / technology / services.

Table2

Micro-level positioning: each Multi-Index Analysis (MIA) level specifies a range of sub-metric levels. (TRL, CRI, MRL, RRL, ARL, ORL) – adapted from Table 1, page 5, in [3].

Sub-metric	Multi Index Analysis (MIA)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
TRL	1	2	3	4	5	6	7	8	9						
MIA_{TRL}	1	2	3	4	5	6	8		9			14			15
CRI	1								2	3	4	5	6		
MIA_{CRI}	8								10	11	12	13	14		15
MRL	1	2	3	4	5	6	7	8	9	10					
MIA_{MRL}	1	2	3	4	5	6	7	8	10			14			15
RRL	1	2	3	4	5	6	7	8	9						
MIA_{RRL}	1	2	3	4	5	6	8		9			14			15
ARL	1	2	3	4	5	6	7	8	9						
MIA_{ARL}	1	2	3	4	5	6	8		9			14			15
ORL	1	2	3	4	5	6	7	8	9						
MIA_{ORL}	1	2	3	4	5	6	8		9			14			15

5. CONCLUSIONS

The AgRL / MIA framework is most beneficial when applied as a forward-thinking design methodology for developing innovative products.

Its strength lies in understanding the issues associated with an unbalanced design and using this insight to improve a product during its development phase.

Instead of concentrating on just one element, design decisions should aim to enhance the overall AgRL / MIA score.

This approach is especially valuable for products with low AgRL / MIA scores, which often arise from exploratory or program-driven research environments where performance is typically measured only by TRL, focusing solely on core functionality.

We argue that this measure is insufficient beyond theoretical research contexts.

Moreover, we propose that our methodology has broader applications beyond individual product assessment. It could also support technology selection, R&D prioritization, and other areas related to emerging technologies.

6. REFERENCES

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METODOLOGIE PENTRU EVALUAREA NIVELULUI "AGREGAT" DE PREGĂTIRE A TEHNOLOGIILOR INOVATOARE

Rezumat: În această lucrare, autorii propun o metodologie pentru evaluarea „nivelului agregat" de pregătire (AgRL) a unui material inovator, respectiv un beton asfaltic nou, cu componente și deșeuri provenite din sticlă și materiale plastice reciclate. Metodologia completează evaluările bine cunoscute ale Nivelului de Pregătire Tehnologică (TRL), cu o metodă de evaluare a TRL, în combinație cu Nivelul de Pregătire a Pieței (MRL), Nivelul de Pregătire Reglementară (RRL), Nivelul de Acceptare a pieței (ARL), Nivelul de Pregătire Organizațională (ORL) și Indicele de

Pregătire Comercială (CRI), luând în considerare influențele lor reciproce, ca un criteriu nou și original de evaluare a nivelului de maturitate, ca o precondiție pentru organizațiile de cercetare care dezvoltă tehnologii inovatoare, ajunse la stadiul "pilot" și care dorește să aibă succes, prin accesarea finanțării investițiilor, publice sau private.

Laura-Florentina BOANȚĂ, Mrs., Ph.D. Candidate, National University for Science and Technology POLITEHNICA Bucharest, Innovation and Technology Transfer Service, laura.boanta@upb.ro, +4-021.4029.584, Splaiul Independentei, 313 Bucharest, Romania

Alexandru MARIN, Mr., Habil. Prof. PhD, Eng., National University for Science and Technology POLITEHNICA Bucharest, Innovation and Technology Transfer Service, alexandru.marin@upb.ro, +4-021.4029.584, Splaiul Independentei, 313 Bucharest, Romania

Miron ZAPCIU, Mr., Habil. Prof. PhD, Eng., National University for Science and Technology POLITEHNICA Bucharest, Innovation and Technology Transfer Service, miron.zapciu@upb.ro, +4-021.4029.584, Splaiul Independentei, 313 Bucharest, Romania

Bogdan-George RÂNEA, Mr., Ph.D. Candidate, National University for Science and Technology POLITEHNICA Bucharest, Innovation and Technology Transfer Service, raneabogdan@yahoo.com, +4-021.4029.584, Splaiul Independentei, 313 Bucharest, Romania

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