TRL-MRL-SRL

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1 LEVELS OF MATURITY

(technology readiness, market readiness, societal readiness)

For decades, maturity models have been used to support research and consulting in the fields of information systems and organizational management. As a result, there is a large amount of literature about them. A recent review of the state of the art[1] discovered 409 relevant papers and a multitude of classification methods, many of which still require meaningful validation.

Information Systems[2], eGovernment applications[3], and Smart Cities[4] have all employed maturity models to assess their current state and progress. The basic idea, which has been criticized for being overly simplistic and supported by a deterministic view of things, is to communicate and share all available information on a given issue with relevant stakeholders in a synthetic and easy-to-grasp manner, in order to stimulate reflection and possibly ignite a reaction. Because of this dual goal of the generic maturity model, the business consultancy community's desire to design and use it as an operational tool for the profession has usually triumphed over the scientific community's desire to eliminate contradictions and conceptual overlaps from the various examples in circulation.

2 TECHNOLOGY READINESS LEVELS (TRL)

Developed by Ray Chase in the 1970s for space exploration technologies and used by NASA in the 1980s, the TRL approach was later fully defined and broadened for use in other industries by

[1] João Batista Sarmento dos Santos-Neto and Ana Paula Cabral Seixas Costa. 2019. Enterprise Maturity Models: A Systematic Literature Review. Enterprise Information Systems 13, 5 (2019), 719-769, DOI: 10.1080/17517575.2019.1575986

[2] Diogo Proença and José Borbinha. 2016. Maturity Models for Information Systems - A State of the Art. Procedia Computer Science 100 (2016), 1042-1049. DOI: 10.1016/j.procs.2016.09.279

[3] Hamad Al-Muftah, Vishanth Weerakkody and Uthayasankar Sivarajah. 2016. Comparing and Contrasting e-Government Maturity Models: A QualitativeMeta Synthesis. In Electronic Government and Electronic Participation, H.J. Scholl et al. (Eds.), IOS Press, 69-79. DOI:10.3233/978-1-61499-670-5-69

[4] Pedro Torrinha and Ricardo José Machado. 2017. Assessment of Maturity Models for Smart Cities Supported by Maturity Model Design Principles. In IEEE International Conference on Smart Grid and Smart Cities (ICSGSC), Singapore, 252-256. DOI: 10.1109/ICSGSC.2017.8038586

John Mankins in 1995[5]. Mankins described and established a framework for comparing and contrasting the maturity of various sorts of technology. While it is a highly useful framework, it is oriented towards technology and innovation push and ignores the concept of innovation or market pull[6]. Other readiness level proponents advise that this paradigm be supplemented by a similar consistent measuring methodology geared toward innovation, integration, or market need. An existing proposed framework, such as innovation readiness[7], demand readiness[8] or system integration readiness[9], could serve as a supplementary framework. Although most technical readiness levels are time-linear, Dent and Pettit point out that a comparable market readiness level may not be.

The TRL concept was introduced in Europe as part of continuous discussions about KETs (Key Enabling Technologies), which have now constituted the backbone of the present EU research, development, and innovation financing structure[10].

TRLs are used to assess a technology's maturity level as it progresses through the research, development, and deployment phases. TRLs are assigned on a scale of one to nine, with nine indicating the most advanced technology[11].

Technology Readiness Levels (TRL) are a form of measurement system for determining a technology's maturity level. Each technology project is assessed against the technology level's parameters, and a TRL rating is issued based on the project's progress[12].

The original TRL developed by NASA is presented in Figure 1.

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[5] Mankins, J.C. Technology Readiness Levels; White Paper; Advanced Concepts Office, Office of Space Access and Technology, NASA (The National Aeronautics and Space Administration): Washington, DC, USA, 1995.
[6] Sune Solberg Hjorth, Alexander Michael Brem. 2016. How to Assess Market Readiness for an Innovative Solution: The Case of Heat Recovery Technologies. for SMEsSustainability 2016, 8, 1152; doi:10.3390/su8111152
[7] Tao, L.; Probert, D.; Phaal, R. Towards an integrated framework for managing the process of innovation. R&D Manag. 2010, 40, 19–30.
[8] Paun, F. The Demand Readiness Level Scale as New Proposed Tool to Hybridise Market Pull with Technology Push Approaches in Technology Transfer Practices. In Technology Transfer in a Global Economy; Audretsch, D.B., Lehmann, E.E., Link, A.N., Starnecker, A., Eds.; Springer: New York, NY, USA, 2012; Volume 28, pp. 353–366.
[9] Sauser, B.; Grove, R.; Forbes, E.; Ramirez-Marquez, J. Integration maturity metrics: Development of an integration readiness level. Inf. Knowl. Syst. Manag. 2010, 9, 17–46.
[10] Pieter Bjørn Larsen, Els Van de Velde, Eveline Durinck, Henrik Noes Piester, Leif Jakobsen and Hanne Shapiro. 2011. Cross-sectoral Analysis of the Impact of International Industrial Policy on Key Enabling Technologies. A Study for the European Commission, DG Enterprise and Industry. Danish Technological Institute and Idea Consult.
[11] Ilenia Bruno, Alessandro Donarelli, Valeria Marchetti, Anna Schiavone Panni, Beatrice Valente Covino, Georges Lobo, Francesco Molinari. 2020. Technology Readiness revisited: A proposal for extending the scope of impact assessment of European public services. ICEGOV2020, 1-3 April 2020, Athens, Greece
[12] https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level

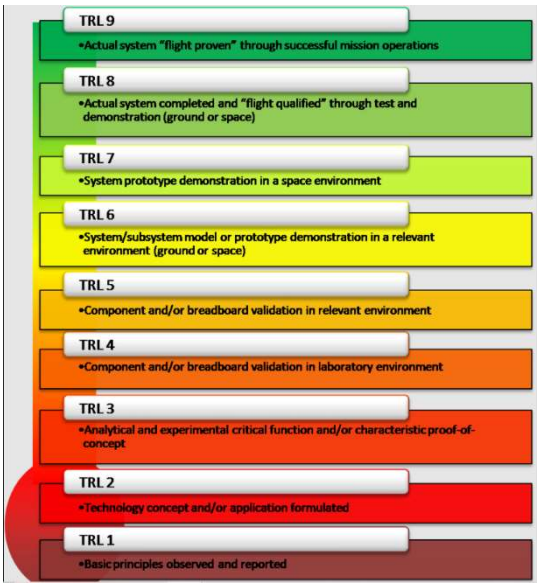

Figure 1. TRL system first developed by NASA

(Source: see footnote 12)

Many organizations have adopted TRLs for their own purposes, with some, such as the European Union (EU), going so far as to standardize NASA readiness-level criteria, making them easier to translate to a variety of industries — not just space exploration.

The following are the nine levels that are widely acknowledged in the EU and around the world[13]:

Level 1: Conceptual fundamentals are observed and reported (Basic principles observed)

Applied research and development begins to take shape as a result of scientific research. Paper research of a technology's basic features could be one of the activities.

Level 2: Formulation of a technology concept and/or application (Technology concept formulated)

The process of invention begins. Practical applications can be devised once basic principles have been observed. At this time, the applications that are being considered are purely hypothetical. Analytic studies are the only activities allowed.

Level 3: Critical analytical and experimental function, as well as proof of concept (Experimental proof of concept)

[13] Sources: https://ec.europa.eu/research/mariecurieactions/sites/default/files/2021-06/wp-13-general-annexes_horizon-2021-2022_en.pdf; https://www.ic.gc.ca/eic/site/080.nsf/eng/00002.html; https://www.twi-global.com/technical-knowledge/faqs/technology-readiness-levels

The research and development process has begun in earnest. Analytical and/or laboratory research are examples of this. Studies and laboratory measurements to validate analytical predictions are examples. Components that are not yet integrated or representational may be included in activities.

Level 4: Component and/or validation in a laboratory setting (Technology validated in lab)

To ensure that basic technology components will work together, they are integrated. Integration of "ad hoc" gear in the laboratory is one of the activities. Analyzing the operational range of a technology parameter is one example. The findings show that the anticipated application performance requirements may be feasible.

Level 5: Validation and/or component testing in a simulated environment (Technology demonstrated in relevant environment)

For testing in a simulated environment, the main technological components are integrated. Laboratory component integration is one of the activities. Technology's dependability has substantially improved. Validation of a semi-integrated system/model of technological and supporting aspects in a simulated environment could be an example.

Level 6: Demonstration of a system/subsystem model or prototype in a simulated environment (Technology demonstrated in relevant environment)

A model or prototype that represents a configuration that is close to what is desired. The prototype system has been tested. Testing can take place in a simulated operational setting or in a laboratory. A prototype system/model could be created and exhibited in a simulated environment as an example.

The pre-commercialization gap for innovations is represented by levels 7 through 9.

Level 7: The prototype is ready to be demonstrated in a real-world setting (System model or prototype demonstration in operational environment)

A significant step forward in technological maturity. Prototype has been developed to a planned operating level and is ready for demonstration in a real-world setting. Prototype field testing is one of the activities.

Level 8: Completed and qualified technology through testing and demonstrations (System complete and qualified)

Technology has been demonstrated to work in its final form and under expected circumstances. The system/model was created and qualified. One example would be the application of TRL 7 knowledge to produce an actual system/model, which is then qualified in an operational context. In the vast majority of cases, this TRL denotes the completion of development. Developmental testing and determining if it will meet operational needs are among the activities.

Level 9: Actual technology that has been successfully deployed in a real-world scenario (Actual system proven in operational environment)

Actual use of the technology in its ultimate form and under real-world conditions, such as those found during operational tests and evaluations. The system/model has been thoroughly tested and is ready for full commercial implementation. Using the innovation in operational settings is one of the activities.

TRLs 1-4 are the emphasis of universities and government funding sources, while TRLs 7-9 are the focus of the business sector.

The name 'Valley of Death' refers to the often-overlooked TRLs 4–7, where neither academics nor the private sector place a high priority on investment. As a result, many promising technologies reach the end of their maturity cycle before being deployed.

UEFISCDI has also developed a document regarding TRL (in Romanian): https://uefiscdi.gov.ro/userfiles/file/PNCDI%20III/P2_Cresterea%20competitivitatii%20economiei%20romanesti/TRL.pdf

Since 2014, the Technology Readiness Level (TRL) scale has been a part of the EU Horizon 2020 Work Programmes, and it has been widely used in the context of ERDF-supported Research, Development, and Innovation investments in many countries and regions across Europe[see 11] (Table 1).

Table 1. TRLs used in EU Horizon framework programmes and ERDF

Maturity level	Description
TRL1	Basic principles observed
TRL2	Technology concept formulated
TRL3	Experimental proof of concept
TRL4	Technology validated in lab
TRL5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL7	System prototype demonstration in operational environment
TRL8	System complete and qualified
TRL9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

The TRL scale has been used during the 2014-2020 programming period, both at EU and national/regional levels. For example, specifying the project's starting and ultimate TRL has been (and continues to be) a condition of the Horizon Europe funding application form, allowing the evaluator to examine the specific, and differential, contribution of the EU grant to facilitating the transition from stage X to stage Y. This method of applying the TRL makes it easier to comprehend where a given project stands on the linear development scale: TRLs 2-4 denote that the initial concept has not yet left the laboratory where it was developed, whereas TRLs 5-7 denote that the concept has left the laboratory where it was developed[see 11].

In the EU Horizon framework programmes TRL is primarily used as a Research and Innovation Policy tool, i.e. to aid decision-making when funding R&D and Innovation projects with public funds. In this way, it helps to clarify and specify the differential impact of the public grant on some, but not all, of the subprocesses that lead to a given level of advancement along the TRL scale. Such progress (from a simple concept to a verified and validated product) can be considered linear, at least when measured in terms of time, but it is shaped in part by the intertwining of numerous concurrent, and often cyclical or iterative, reflective and experimental processes.

3 MARKET READINESS LEVELS

Although the term "market readiness" is frequently used, particularly in the context of commercial consulting, there is no scientific consensus on what such a framework should consist of[14].

2.1. READINESS FOR SYSTEM INTEGRATION (SIRL)

Sauser et al.[15] propose a system readiness level (SRL) framework based on a technology readiness level (TRL) and an integration readiness level (IRL), which is intended to address the issue that TRL only addresses the technology itself, rather than how it might technically integrate into a new or existing system (Table 3). Regardless of how mature a technology is, it will fail if it cannot communicate with other technologies.

Table 3. Integration readiness levels (IRL)

Maturity level	Definition
IRL1	An interface (i.e., physical connection) between technologies has been identified with sufficient detail to allow characterization of the relationship.
IRL2	There is some level of specificity to characterize the interaction (i.e., ability to influence) between technologies through their interface.
IRL3	There is compatibility (i.e., common language) between technologies to orderly and efficiently integrate and interact.
IRL4	There is sufficient detail in the quality and assurance of the integration between technologies.
IRL5	There is sufficient control between technologies necessary to establish, manage and terminate the integration.
IRL6	The integrating technologies can accept, translate and structure information for its intended application.
IRL7	The integration of technologies has been verified and validated with sufficient detail to be actionable.

[14] How to Assess Market Readiness for an Innovative Solution: The Case of Heat Recovery Technologies for SMEs, Sune Solberg Hjorth * and Alexander Michael Brem, 2016.
[15] Sauser, B.; Verma, D.; Ramirez-Maquez, J.; Grove, R. From TRL to SRL: The concept of systems readiness levels. In Proceedings of the Conference on Systems Engineering Research, Los Angeles, CA, USA, 7 April 2006; pp. 6–7.

In contrast to TRLs, all of the IRLs can be developed through prototyping before a finished product is available. This means that the IRL levels can be achieved (and should be) before TRL 9 or even 8. Following that, Sauser et al. propose five system readiness levels (SRL), which are presented in Table 4 below.

Table 4. System readiness levels (SRL)

Maturity level	Name	Definition
SRL1	Concept refinement	Refine the initial concept. Develop system / technology development strategy.
SRL2	Technology Development	Reduce technology risks and determine and appropriate set of technologies to integrate into a full system.
SRL3	System Development and Demonstration	Develop a system or increment of capability; reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for productibility; ensure affordability and protection of critical program information; demonstrate system integration, interoperability, safety and utility.
SRL4	Production and Development	Achieve operational capability that satisfies mission needs.
SRL5	Operations and Support	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle.

In order to grade the interoperability of the entire system, the final SRL framework is an aggregate of the various TRLs and their IRLs in relation to other technologies relevant to their integration[16].

[16] Dent, D.; Pettit, B. Technology and Market Readiness Levels; Dent Associates White Paper 11-01; Dent Associates Ltd.: Winchester, UK, 2011.

2.2. Demand Preparation

Florin Paun has established a readiness framework focused on displaying the gap, or asymmetry, between technology push, which is primarily ascribed to TRL, and technology pull. He relates market pull to a demand readiness level (DRL)[see 8], by measuring the level of market pull proportional to the level of technical push (Table 5)[17].

Table 5. Demand readiness levels (DRLs) paired with technology readiness levels (TRLs)

DRL maturity level	DRL description	TRL description	TRL maturity level
1	Occurrence of feeling "something is missing"	Market certification and sales autorization	9
2	Identification of specific need	Product industrialization	8
3	Identification of the expected functionalities for a new product / service	Industrial prototype	7
4	Quantification of expected functionalities	Field demonstration of the whole system	6
5	Identification of system capabilities	Technology development	5
6	Translation of the expected functionalities into needed capabilities to build the response	Laboratory demonstration	4
7	Definition of the necessary and sufficient competencies and resources	Research to prove feasibility	3

[17] Paun, F. "Demand Readiness Level" (DRL) a New Tool to Hybridize Market Pull and Technology Push Approaches: Evolution of Practices and Actors of Eco-Innovation; ANR-ERANET Workshop: Paris, France, 2011.

8	Identification of the experts possessing the competencies	Applied research	2
9	Building the adapted answer to the expressed need in the market	Fundamental research	1

For example, ONERA, the French Space Laboratory (Office National d'Etudes et de Recherches Aérospatiales), has actively employed DRL in conjunction with TRL to build an ecosystem of SMEs around ONERA for commercializing its inventions. The argument offered was that SMEs were better in line with market demands and could mediate the transfer of technology to industry for the aim of commercialization through the framework of DRL and TRL[see 8].

4. SOCIAL (SOCIETAL) READINESS LEVELS (SRL)

This idea refers to how prepared society as a whole is to absorb a specific innovation, whether technological or social. SRL is a comprehensive decision that takes into account ethical, legal, social, and economic considerations. Its levels span from the point at which a specific societal need begins to arise and is recognised as such, through the point at which society uses relevant innovations to address that need. https://www.techethos.eu/glossary/societal-readiness-level-srl/

The SRL was developed by Innovation Fund Denmark[18] to determine the level of public acceptability of a technology, product, process, or intervention. It is based on the premise that all innovation, whether technical or social, must be integrated into the societal environment. As a result, the higher the SRL, the greater the level of integration.

The SRL has nine possible stages, which are listed in Table 6 below.

[18] Innovation Fund Denmark. 2018. Societal Readiness Levels (SRL) defined.

Table 6. Societal Readiness Levels (SRLs) scale

Maturity level	Definition
SRL1	Identification of the generic societal need and associated readiness aspects
SRL2	Formulation of proposed solution concept and potential impacts; appraisal of societal readiness issues; identification of relevant stakeholders for the development of the solution
SRL3	Initial sharing of the proposed solution with relevant stakeholders: a limited group of the society knows the solution or similar initiatives
SRL4	Solution validated through pilot testing in controlled environments to substantiate proposed impacts and societal readiness; a limited group of the society tests the solution or similar initiatives
SRL5	Solution validated through pilot testing in real or realistic environments and by relevant stakeholders; the society knows the solution or similar initiatives but is not aware of their benefits
SRL6	Solution demonstrated in real world environments and in cooperation with relevant stakehorlders to gain feedback on potential impacts; the society knows the solution or similar initiatives and awareness of their benefits increases
SRL7	Refinement of the solution and, if needed, retesting in real world environments with relevant stakeholders; the society is completely aware of the solution's benefits, a part of the society starts to adopt similar solutions
SRL8	Targeted solution, as well as a plan for societal adaptation, complete and qualified; society is ready to adopt the solution and have used similar solutions on the market
SRL9	Actual solution proven in relevant societal environments after launch on the market; the society is using the solution available on the market

According to Innovation DK, stages SRL 1-3 describe early work in a research project, such as proposing and testing a technical and/or social solution to a technical or societal problem on a preliminary basis. Here, reflections on societal readiness for the idea and proposed solution(s)

are needed, as well as identification of essential stakeholders and how to include them (such as end users, the right communities, etc.)[19].

The actual solution(s), the research hypothesis, and testing it/them in the relevant context in collaboration with important stakeholders, while focusing on effect and society's readiness for the product, are represented by stages SRL 4–6. Expectations for societal adaptation must be expressed in concrete terms and, to the extent practicable, be included in these stages[see 19].

The latter stages of the research project, including refining the solution(s), implementation, and distribution of results and/or solutions, are covered by SRL 7-9. Here will be carried out the plan for addressing societal readiness on a practical level in order to acquire effect, create awareness, and disseminate findings, among other things[see 19].

Even if we consider the target answer to be technological, the connection between TRL and SRL is very close and direct.

SRLs 1-2 represent a Research and Development team's developing awareness of the presence of a societal preparedness concern. SRLs 3-6, on the other hand, are concerned with the increasing integration of social stakeholders (such as potential users or other stakeholders)[see 11].

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Organisational Readiness Levels (ORL)

See: https://ec.europa.eu/isa2/sites/default/files/technology_readiness_revisited_-_icegov2020.pdf

Legal Readiness Levels (LRL)

See: https://ec.europa.eu/isa2/sites/default/files/technology_readiness_revisited_-_icegov2020.pdf

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[19] https://innovationsfonden.dk/sites/default/files/2019-03/societal readiness levels - srl.pdf

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