A Conceptual Technology Readiness Loop Model Through Systematic Review and Thematic synthesis

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Abstract: Technology readiness of products, services, organisations and consumers have been widely studied from different perspectives. This research aims to synthesize the themes of technology readiness through a systematic review of articles published in the time-period of 1995-2018 and further develop a technology readiness loop model for commercial new technology development. The applicability, use of the model and further research directions were recommended.

Keywords: Technology Readiness, PRISMA, Systematic Review, TRLOOP

1. Introduction

Assessing technology readiness is one of the crucial processes to manage the research and development growth and management decision making in terms of new technology development, technology adoption and transition. Conceptually, the tool for assessing Technology readiness level (TRL) was first developed by NASA in the late 20th century and adopted by various public and private entities. It is widely used for technology readiness assessment and the trend is expected to grow (Mankins, 2009). In addition, in the late 20th century and early 21st Century, technology readiness has gained attention among academic research from different perspectives, especially marketing. A reasonable volume of research has been published in various academic domains. However, even space explorations, which were purely science and exploration research, are getting commercialized (spacex, nd) in the 21st century. On the other hand, technology readiness is intensively studied in the marketing domain. Thus, this research aims to explore technology readiness research and develop an integrative conceptual framework for technology readiness.

2. Research Method and Article Selection

Technology Readiness is a generic keyword and multidisciplinary in nature. Thus, this research adopts a mix of scientometrics and exploratory literature review (Zarkada, 2012) to synthesis the thematic evolution of technology readiness research in the first 20 years of the 21st century using bibliometrix (Aria et al, 2017) package in R (R Core Team, 2020) programming language. A keyword search with "technology readiness" and exact keyword filter of "Technology Readiness Level" results in 471 articles in the SCOPUS database. So, this research adopts scientometrics, theme-based, systematic review (Sharafuddin, et al., 2020) and draws the results with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method to explore and synthesize the factors of technology readiness. The keywords used to identify the articles from the SCOPUS database are provided in Table 1.

Table 1. Keywords used for article selection

| TITLE-ABS-KEY ("Technology Readiness") AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (EXACTKEYWORD, "Technology Readiness Levels") OR LIMIT-TO (EXACTKEYWORD , "Technology Readiness") OR LIMIT-TO (EXACTKEYWORD , "Technology Readiness Level")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) |
| --- |

3. Main Information of the Articles selected

The main information of the articles selected for the study is summarized in Table 2. The bib file consisted of 312 sources and 471 documents with 19.23 average citations per document with 22,778 citations within the SCOPUS database. We further calculated the annual scientific production of articles in this research domain. The annual growth of scientific production in this research domain was 16.72% (Figure 1).

Table 2. Main Information

| Description	Results
Timespan	1995-2018
Sources (Journals, Books, etc)	312
Documents	471
Average years from publication	4.82
Average citations per documents	19.23
Average citations per year per doc	2.784
References	22778
Document Type	
article	471
Document Contents	
Keywords Plus (ID)	3999
Author's Keywords (DE)	1544
AUTHORS	
Authors	1862
Author Appearances	1996
Authors of single-authored documents	50
Authors of multi-authored documents	1812
Authors Collaboration	
Single-authored documents	56
Documents per Author	0.253
Authors per Document	3.95
Co-Authors per Documents	4.24
Collaboration Index	4.37
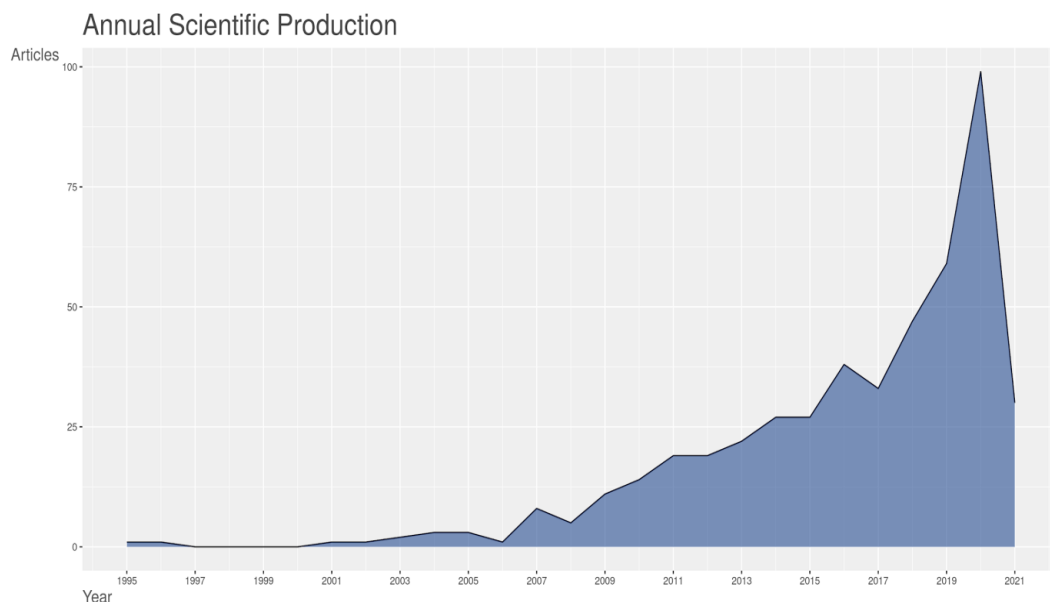
Figure 1. Annual Scientific Production

Co-occurrence network of Author's Keywords

The co-occurrence network of author's keyword was computed to analyze the conceptual structure using "Salton" normalization and "Edge Betweenness" clustering algorithm with fifty nodes to understand the research front. The co-occurrence analysis revealed three clusters of author's keywords - (1) "Technology Readiness

Level", (2) "Technology Readiness" and (3) "System Readiness Level" along with other unique keywords such as "manufacturing", "electronic commerce", "blockchain", and "biomass" (Figure 2. Co-Occurrence Network Analysis).
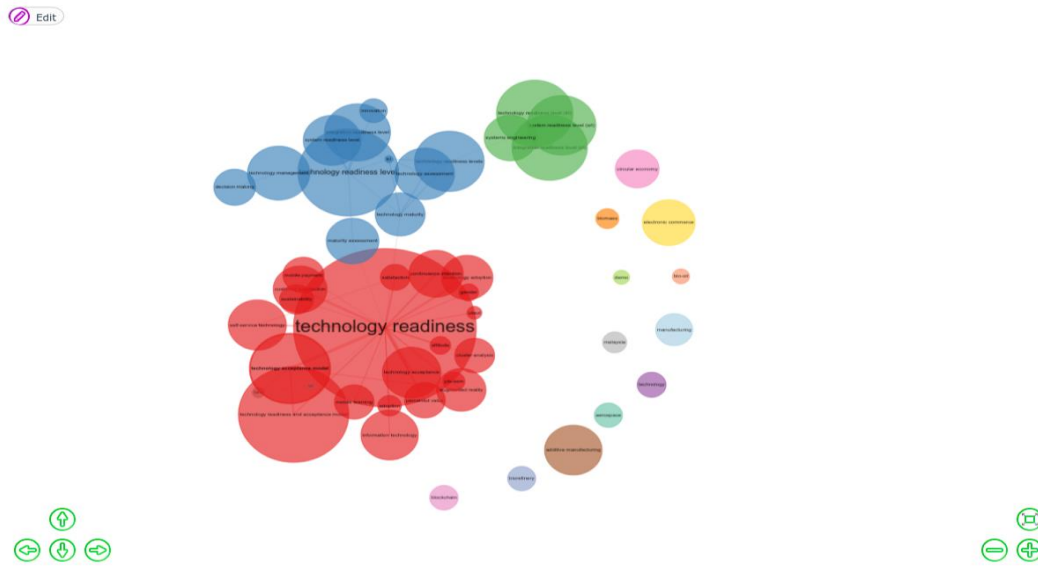
Figure 2. Co-Occurrence Network Analysis

4. Themes through Co-occurrence Network Analysis

In the next stage, the researchers further explored the themes through a systematic approach to article selection. The most crystal-clear method for reporting systematic reviews is through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. The PRISMA model for article selection is provided in Figure 3.
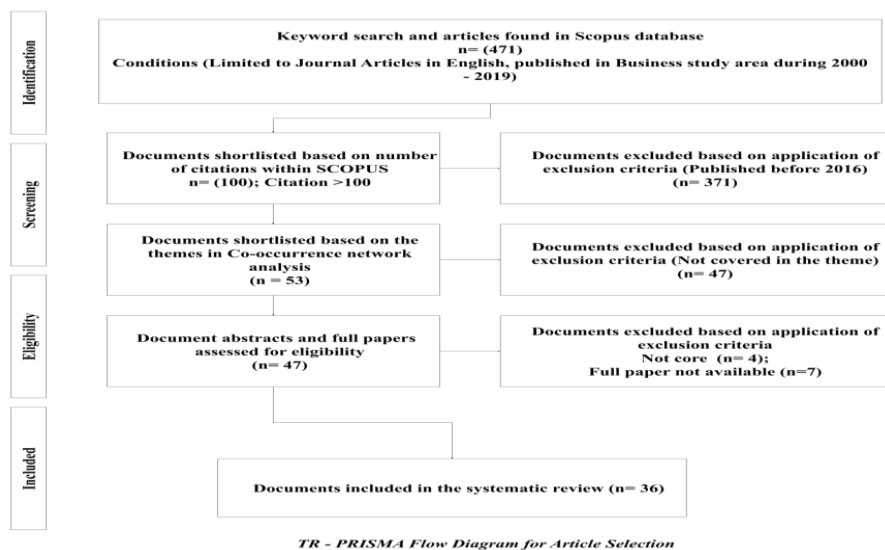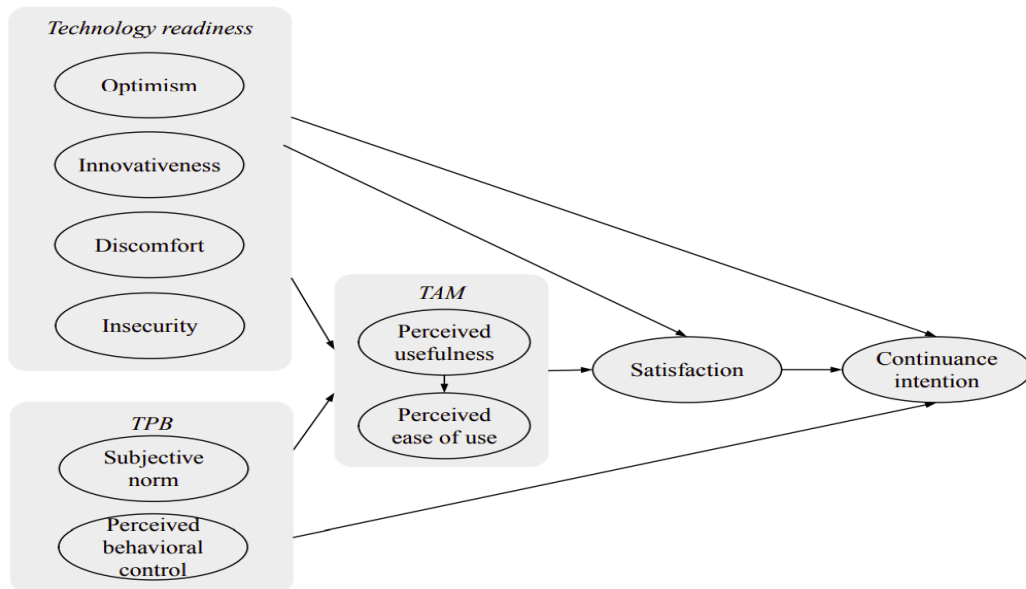

Figure 3. PRISMA - Technology Readiness

4.1. Technology Readiness Levels

The Technology readiness level framework of the European Union (European Union, 2016) is similar to the one developed by NASA (Sadin, Povinelli & Rosen, 1989; Mankins, 2009). It consists of nine levels, namely (TRL 1) "basic principles observed", (TRL 2) "technology concept formulated", (TRL 3) "experimental proof of concept", (TRL 4) "technology validated in the lab", (TRL 5) "technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)", (TRL 6) "technology demonstrated in relevant environment industrially relevant environment in the case of key enabling technologies", (TRL 7) "system prototype demonstration in operational environment", (TRL 8) "system complete and qualified", (TRL 9) "actual system proven in operational environment (competitive manufacturing in the case of key enabling

technologies; or space)". However, the High-Level Expert Group on Key Enabling Technologies (HLG-KET 2011) proposed for universal adoption of the Technology Readiness Level scale for assessing all industries and sectors (Héder, 2017). Leitão, Colombo & Karnouskos, (2016) used the technology readiness levels as a benchmark to assess the levels of four (SOCRADES, IMC-AESOP, GRACE, and ARUM) European innovation projects. Thus, proving that the TRL is a reliable scale for assessing the level of advancement in industrial cyber-physical systems. The TRL scale is also adopted in various public and private entities. The Electric Power Research Institute (EPRI) adopted the TRL scale of NASA to estimate the adoption of software technologies such as Desktop and Web eMedia, Computer-Based Training, Complicated spreadsheets Desktop, Server/Enterprise, Software Implemented via a Commercial Software Platform, Software Extension, Web Application, Web Service, Mobile Application and Business Service Agreement (BSA). They further simplified the TRL scale based on 3 lifecycle types. Namely (1) prototype (TRL 1 & 2), (2) Proof-of-concept (TRL 3-5) and Production (TRL 6-9) (EPRI, ND). On the other hand, Bhown & Freeman (2011) used TRL scale to assess the post-combustion carbon dioxide capture technologies of power plants. The authors noted the limitations of TRL 1. The TRL 1 level of data is mostly unavailable because it is just the basic principle. Hence, the research used the scale from TRL2 to TRL 9. But, found that most of the carbon capture technologies of power plants was at the stages of TRL 2-4. Thus, the TRL scale was proved suitable for assessing the power plants developments in terms of carbon capturing. Morstyn, Hredzak & Agelidis (2016) evaluated the micro-grid control strategies in distributed ES systems using technology readiness level scale. They found the TRL ranges between 2-4. Rybicka, Tiwari, & Leeke (2016) adopted the three-level (Level 1: Lab-scale; Level 2: Pilot-scale; Level 3: Commercial Scale) concept of Yang et al (2012) and diffused it into the TRL scale with TRL 1-3 as level 1, TRL 4-6 as level 2 and TRL 7-9 as level 3 to assess the technology readiness level of recycling composite materials. The authors developed a technology card with TRL scale to gain expert opinion. Macdonald & McInnes (2011) addressed the limitation of the technology readiness level scale. The authors mentioned that the scale could be helpful in finding the readiness/maturity of a particular technology at a specific time in a schedule. However, it does not include any intelligence or any particulars on "what's & how's" of the factors for reaching the higher level. Ramasubbu et al., (2005) developed a KPA (Key Process Areas) based process maturity index to assess the process maturity level in collaborative technologies of distributed development. The authors simplified the stages of the maturity level into three; (1) initiation level, (2) Consolidation level, and (3) High productivity level. "Technology readiness" was assessed along with "common ground", coupling in work" and "collaboration readiness". The authors defined technology readiness as both personal capabilities and development infrastructure. However, those approaches were much of an Engineer's point of view and have either limited or no attention towards the other Internal and external factors and the market success of the technology. This is due to the nature of studies. The studies mentioned in the above literature were focused on either research entities or public entities. Mankins (2009) integrated the technology readiness scale and risk assessment scale to develop an integrated approach of assessing the conceptual risks involved in moving to the higher level of technology readiness. Sauser et al., (2006, 2008) developed the concept and method for assessing the system readiness level of systems engineering. This is one of the pionier studies in the advancement of TRL scale expansion research. The authors argued that technologies are not stand-alone, and they are connected with other technologies through integration. Hence, introduced integration readiness level and assessed system readiness level with both technology readiness and integration readiness levels. Heslop et al., (2001) developed the "Cloverleaf Model" with Market, commercial, management and Technology readiness as scores for assessing the readiness of entities in Technology transfer of self-service technologies. Thus, one of the first multi-dimensional approaches for assessing technology readiness. However, it was not related to NASA's TRL scale, but a "Business and Management" approach with results from data collected from the respondents. Kurata (2016) used the Technology readiness scale to assess the practical use of accident tolerant fuel (ATF) in commercial light water reactors (LWR). The author grouped the technology readiness levels into three groups of phases (1) proof of concept, (2) Proof of principle and (3) Proof of performance and used the industrial process approach (Fuel "design", "performance", manufacturing, "plant performance", "safety", "approval", "storage and transportation" and "Reprocessing & waste disposal") and related research & development fields to scale the Technology readiness levels. This approach is precise in terms of the Industrial process. Ramirez et al (2009) also noted the limitations of adopting the Technology Readiness scale in a system context where multiple technologies must interplay to successfully develop the overall system. Thus, adopted the system readiness level (SRL) of Sauser et al (2006, 2008) which included Integration readiness level to assess the life cycle position and system's developmental maturity. To the best of the author's knowledge, this is the first research that integrated customer (User) needs in TRL through IRL, SRL, & SRLMax. The authors also noted that technology maturation and integrations must meet the evolving user needs to provide the appropriate solution. With due consideration to the emerging commercial space operations and the need for aligning air, space, agencies, industries, parts and product use, and to promote best practices, Straub (2015) proposed an extension to the Technology readiness level scale of NASA. The author proposed "Proven Operations" as TRL 10. The author also proposed descriptions for software and hardware separately along with exit criteria, i.e., the maturity assessment criteria for all the ten levels of TRL. From the above literature, it is

clear that the scale of Technology Readiness Level, primarily used in Space research has been adopted in various research areas and also evolved to suit the considerations for commercial use and evolving consumer needs.

On the other hand, consumers' mental readiness towards adopting new technology has emerged through theories of reasoned action (Davis, 1985), theory of planned behaviour (Fishbein & Ajzen, 1980; Ajzen, 1991), technology acceptance model (Davis et al., 1989); and technology readiness index (Parasuraman, 2000). Later, Lin et al., (2007) integrated technology acceptance and technology acceptance to develop the "Technology Readiness and Acceptance" model. These theories and models dominate the technology readiness in the marketing context and individual perspective. The "Technology-Organization-Environment" theoretical framework developed by Tornatzky et al., (1990) dominates technology readiness from an organizational perspective.

Figure 4. Integrated TR, TPB. TAM Framework Source: Chen, Chen & Chen (2009).

4.2. T-O-E Framework and Technology Readiness

Low et al., (2011) used the Technology-Organization-Environment framework to assess the factors determining high-tech industries cloud computing adoption. The authors found that the relative advantage of adopting the new technology is one of the influencing factors of high-tech organizations' readiness in adopting new technologies.
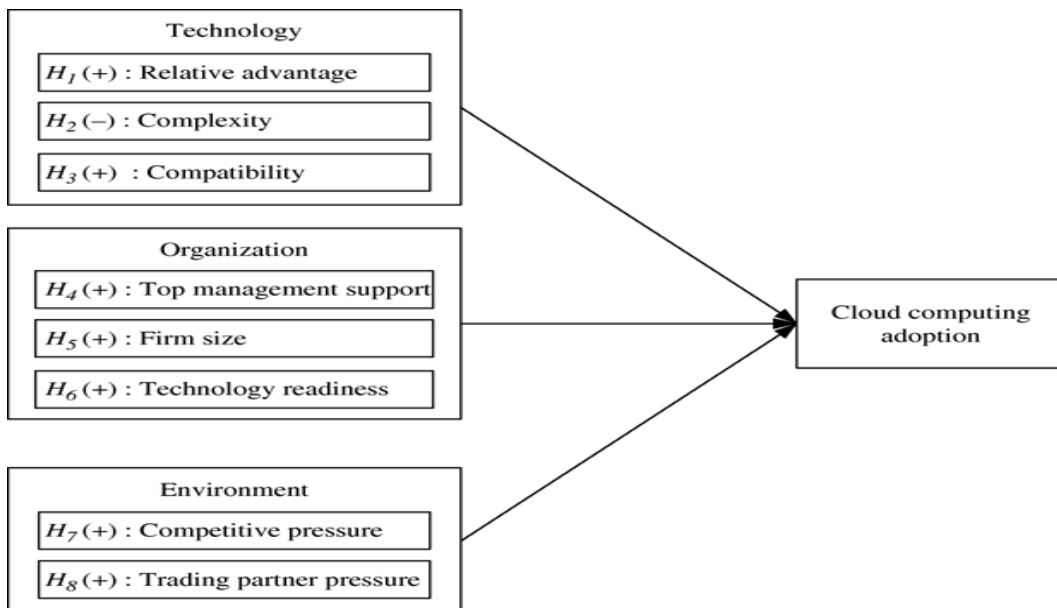
Figure 5. T-O-E Framework. Source: Low, Chen, & Wu (2011).

Zhu et al., (2004) extended the T-O-E framework with e-business value and found that technology readiness is the strongest factor in creating value for electronic businesses. Oliveira & Martins (2010) included 27 European

countries and two industries (tourism & telecommunication) as control variables in the T-O-E framework to assess the determinants of their electronic business adoption. The study revealed that technology readiness is one of the important factors determining the electronic business in both sectors and it varies among different countries.

4.3. Social Identity Theory

Westjohn et al., (2009) hypothesized "Cosmopolitanism", "Global Identification", "Promotion Focus" & "Prevention Focus" as direct and indirect factors affecting technology readiness and technology usage. The model was based on social identity theory.

4.4. Technology Readiness Index (Consumer's mental readiness)

The Technology readiness Indexes 1.0 (Parasuraman,2000) and 2.0 (Parasuraman & Colby, 2015) are the most influential models for assessing technology readiness at the individual consumer level. It was constructed based on 4 dimensions: Positive - (1) Optimism, (2) Innovativeness; Negative- (3) Discomfort & (4) Insecurity. The scales are widely used in evaluating consumer psychology in service industries. One of the recent changes in the Aviation industry is passenger self-check-in services. Liljander et al., (2006) evaluated the attitude and consumer behaviour of European Air passengers in adopting passenger self-check-in services using the TRI along with service quality, satisfaction and loyalty. The research revealed that optimism (control, freedom of mobility and convenience) were the major technology readiness factors influencing the adoption of self-service services in the airline industry. Chung et al., (2015) hypothesised technology readiness as an important personal factor and tested its relationship with stimulus factors and situational factors in using augmented reality for developing smart tourism. The research found that technology readiness can be the predictor of perceived usefulness. Chen et al., (2009) synthesized the Technology acceptance model, theory of planned behaviour and technology readiness to assess the customer readiness in using self-service technologies continuously. This is one of the most refined steps adopted in assessing customer readiness and is one of the most influential articles in this research domain. Lin et al., (2007) used the TAM model to assess the relationship between technology readiness and satisfaction with augmented reality and its impact on destination loyalty. The authors found that Technology readiness is conditioning user satisfaction. This is also one of the very few papers that emphasize on the integrated work of product/service designers and marketers. Another study that accentuates the cyclical relationship between service design, service offering and customer's technology readiness. The authors also underlined that integrating marketing information in research and development is the key element of the successful delivery of online services. Wang, So, & Sparks (2017) emphasized on incorporating users' technology readiness and the technology-enabled travel services in the Airline sector. Thus, making the technology and technology readiness information of users bi-lateral information for offering a better user experience.

Technology readiness was also used as a scale/sub-scale for market segmentation (Tsikriktsis, 2004; Zhu, Z., Nakata et al., 2007), Blockchain adoption (Kamble et al., 2019), consumer complaints and service recovery (Mattila & Mount, 2003), Internet banking (Yousafzai & Yani-de-Soriano, 2012), and C2C platform functionality (Lu et al., 2012). Aboelmaged (2014) evaluated the e-maintenance readiness (using TRI framework) by integrating the TOE framework of manufacturing firms. This research was conducted in the pre-implementation stage. Son & Han (2011) used TRI but focused on adoption and post-adoption consumer behaviour and identified that technology readiness influences repurchase intentions. These researches can be conceptualized and connecting in the final stage of the Technology Readiness Level scale (TRL- 9/10).

5. Conceptual Model

Several readiness level scales have been developed and have been adopted by various public, private and research entities. However, the risks of moving from one TRL to another in a scenario where new technology development for commercial purposes is less explored. Thus, this research proposes a "Technology Readiness Loop Model" in which New technology development includes the development of both software and hardware solutions and offering as a system. Thus, the readiness level of multiple technologies and their integration (Mankins, 2009) forms the scale for system readiness level (Sauser et al., 2006, 2008). We further extended the scale from TRL 1-9 to 10 similar to Straub (2015). However, in our model TRL 10 is aimed at further development of the same technology based on market intelligence. Thus, TRL 10 is upgrades/updates of the same technology to suit the evolving market needs and competition. The input for market intelligence depends on the type of solution offered. If it is a B2B solution, then T-O-E framework can be used and if it is a B2C solution, TRI and TAM frameworks can be used to obtain market adoption, satisfaction, bug reports and feedback from the consumer markets. Anyway, the market intelligence data is not limited to TRL 10. It may be the deciding factor for all levels of Technology readiness to compute the investment, risk, and returns of advancing through the Technology readiness levels to offer suitable technology-based solutions. Thus, we call it as "TRLOOP" - Technology Readiness Loop.
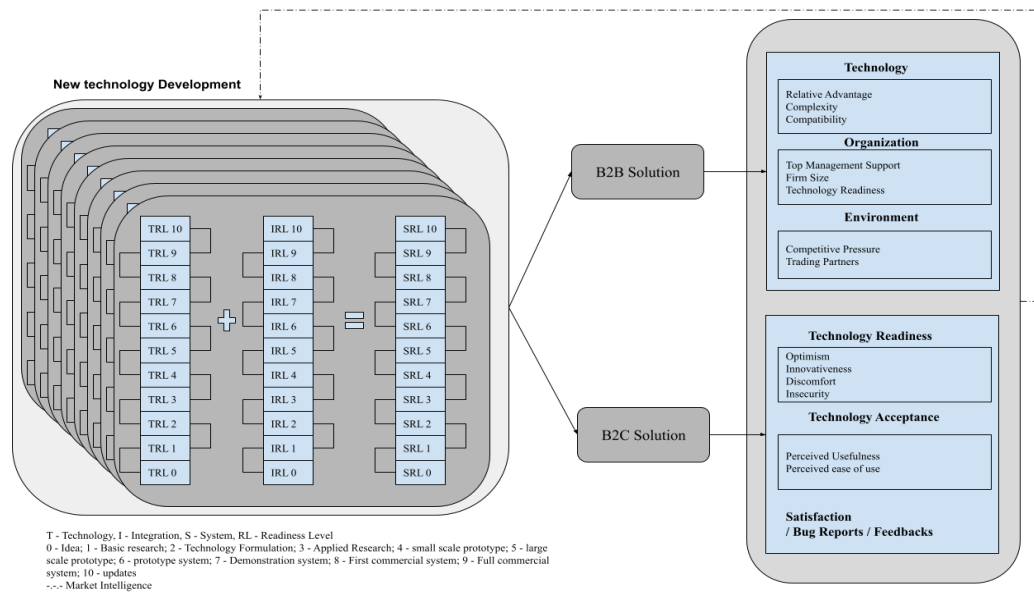
Figure 6. Technology Readiness Loop – TRLOOP**.**

6. Conclusion

With fast changes in the 21st century and the evolution of 5G, Internet of Things, Industry 4.0 technologies, the challenge of new technology development is growing. On the other hand, small and medium enterprises and consumer markets are facing various challenges such as rising labor costs, production costs and competition. Thus, the proposed TRLOOP model can be used as a scale for identifying, benchmarking, developing and improving new technological solutions. The TR levels in the framework are kept generic so that they can be adopted and modified to suit different socio-cultural, economic, business environments. Some of the relevant research articles might have been missed in the scientometric analysis due to the selected keywords and database. There might also be a bias in reporting the scientometrics due to the above-said limitations. However, the objectives were achieved with the selected database.

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45. The results reveal the evolution of TRL research in the domains of business, management, accounting, economics, econometrics, finance, social sciences and decision science. Though TRL is highly related to the engineering domain, its applicability in the field of business decision making science is discussed in this research outcome. Further directions of TRL research in the technology and business administration is also provided.

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