ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 09, Issue, 11, pp. 31947-31952, November, 2019

REVIEW ARTICLE OPEN ACCESS

METRICS FOR ANALYSIS OF TECHNOLOGICAL MATURITY OF ACADEMIC SPIN-OFFS THROUGH TECHNOLOGY READINESS LEVELS

***[1]Carlos Eduardo Barbosa, [2]John Hebert da Silva Felix, [3]Samuel Façanha Câmara and [4]Olienaide Ribeiro de Oliveira Pinto**

[1]Master of Sociobiodiversity and Sustainable Technologies, Institute of Engineering and Sustainable Development, University of International Integration of Afro-Brazilian Lusophony,62790-970, Redenção-CE, Brazil.[2]Institute of Engineering and Sustainable Development, University of International Integration of Afro-Brazilian Lusophony, 62790-970, Redenção-CE, Brazil.[3]Postgraduate Program in Administration, Ceará State University, 60714-903, Fortaleza-CE, Brazil.
[4]Institute of Engineering and Sustainable Development, University of International Integration of Afro-Brazilian Lusophony, 62790-970, Redenção-CE, Brazil

ARTICLE INFO

Article History:
Received 17th August, 2019
Received in revised form
19th September, 2019
Accepted 29th October, 2019
Published online 30th November, 2019

Key Words:
Technological innovation. Academic spin-off. Biotechnology. Technological maturity. TRL. UECE.

****Corresponding author:***
Carlos Eduardo Barbosa

ABSTRACT

This work aimed to develop a framework for assessing the technological maturity of companies that are born from research groups of educational institutions or research centers. These companies, commonly called academic spin-offs, usually start their activities after participating in incubation processes performed by academic incubators, where they learn to direct their efforts to business maturity, disregarding the technological maturity required for the development of their final product. The assessment framework created analyzes and classifies the technological maturity of these companies from four different approaches of analysis, namely: TRL Calculator work-based approach, approach based on NBR 16290:2015, Weighted calculation approach and Percentage of levels approach, these last two proposals being developed by the authors. The analyzed sample is composed of three academic spin-offs of the Biotechnology sector incubated by INCUBAUECE. The results indicated that the companies have high levels of technological maturity, in addition to indicating which activities the companies had greater difficulty in performing and, finally, the instrument used proved an excellent guide for the technological development of these companies.

Copyright © 2019, Carlos Eduardo Barbosa et al. *This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.*

Citation: Carlos Eduardo Barbosa, John Hebert da Silva Felix, Samuel Façanha Câmara and Olienaide Ribeiro de Oliveira Pinto. 2019. "Interprofessional collaboration in primary health care: An integrative review", *International Journal of Development Research*, 09, (11), 31947-31952.

INTRODUCTION

Academic spin-off (ASO) is a company created to explore an intellectual property generated from research work developed in an academic institution (SHANE, 2004). Among the main characteristics of a ASO, we can mention: (1) are companies created in universities; (2) are created to explore technological innovations, patents and the knowledge accumulated by researchers during academic activities; (3) are founded by at least one member of the universities (professor, student or employee). Generally, the agents of the innovation process within the university are the researchers, graduate students, professors and the Center for Technological Innovation (NIT) - when it exists - given that the knowledge accumulated by them ends up providing the new products and/or innovative technologies for society and for the companies that will be developed by them (PEDROSI FILHO, 2014). Even these companies possessing a small company profile, and many times having a reduced staff, the spin-offs created through scientific research have great economic importance for the innovation activity and for the region where they are inserted.

The support of the parent organization, in the case of universities, is fundamental, especially in the early stages of the spin-off. The transfer of external competences to the technical area provides the necessary support for the company's management activities, in addition to providing access to its network of contacts. Academic incubators generally give this contribution (SANTOS; TEIXEIRA, 2012). Society also benefits directly from the creation of these companies, through the generation of foreign currency, jobs and technologies that lead to the technological, economic and social development of the region. Considering the context of biotechnology companies, the formation of spin-offs that offer innovative products related to human and animal health, food is of extreme importance for humanity. These products may enable a better quality of life for living beings, as well as allow the development of better quality and healthier foods, besides allowing a better distribution of these foods and advances in the energy sector.

The academic spin-offs of biotechnology, as well as most spin-offs incubated in Brazil, are concerned only with corporate maturity, neglecting the assessment of technological maturity.
Technological maturity is a set of reproducible processes (which can be repeated over time) for the design, manufacture, testing and operation of an element (in this case, the final product of the company). These processes aim to meet a set of performance requirements defined by the customer in an actual operating environment, in which they have natural conditions, and which restrict the product of its design definition to its operation. One of the available tools for technology assessment that allows defining their respective degree of technological maturity is Technology Readiness Levels – TRL (ISO, 2013). TRL levels are a systematic measurement system that helps to assess the maturity of a technology and to compare maturity between different types of technology (MANKINS, 1995). TRL levels 1 to 3 comprise the design stages of innovation, while TRL levels 4 to 6 comprise the development stages of the innovative product. Finally, levels TRL 7 to TRL 9 indicate the stages of innovation completion (ISO, 2013). A technology reaches the level of maturity corresponding to TRL 9 when it is well defined by a set of reproducible processes for the design, manufacture, testing and operation of this technology. In addition, the product (defined in ISO vocabulary as an element) meets a set of performance requirements in an actual operating environment. Therefore, the instrument created aimed to develop a framework for assessing the technological maturity of academic spin-offs from the analysis of the completeness of the requirements of each TRL level, indicating, finally, the TRL level that best represents the current state of the technology.

MATERIALS AND METHODS

This research used the strategy of study of multiple cases to analyze the degree of technological maturity of 03 (three) academic spin-offs of the branch of Biotechnology that have their headquarters in the state of Ceará and that were incubated by the Incubator of Companies and Center for Technological Development and Innovation of the State University of Ceará - INCUBAUECE. For this, the definitions of the TRL levels indicated by the Brazilian Standard NBR ISO 16290:2015 were used for the construction of the evaluation instrument, making the necessary adaptations to the scope of Biotechnology. In order to collect data on incubated companies, a questionnaire was created based on the TRL Calculator 2.2 application by William L. Nolte, Brian C. Kennedy and Roger J. Driegiel Jr. (2003). This application evaluated the technological maturity of companies in the field of Information Technology. Taking into consideration the proximity between biotechnology and information technology (target companies of the TRL Calculator), the instrument created used the criteria common to both technological branches mentioned, making adaptations, when necessary, considering the specificities of the biotechnology branch.

The questionnaire is divided into scales, similarly to the TRL Calculator, in such a way that the ASO manager can start to assess the maturity of the scale in an increasing manner. For example: the interviewee starts verifying if the technology has already performed the tasks of observation and registration of basic principles, tasks inherent to TRL level 1, such as:

- Have the basic principles of technology been identified?
- Have potential applications for the technology been identified?
- Have the studies that confirm the basic principles been documented?

For each task, the interviewee must indicate the percentage of how complete the respective task is, using a linear scale from 0 (zero) to 10 (ten). Thus, the linear scale is divided into percentages of 10% (0%, 10%, ..., 90% and 100%) and the interviewee can indicate which percentage best demonstrates the reality of the task in his company. If the activity has not been started or the user has not been able to inform the progress of the respective activity, or if the user does not know the activity, the user shall indicate the value "0", corresponding to 0%. Similarly, if the task has been completely executed, the interviewee must choose the value 10, representing 100%. The questions are grouped into categories of related questions. By grouping the related questions, the instrument forces the user to consider all the relevant questions for a given topic at the same time. This helps to avoid confusion, since all questions that ask about "Level of knowledge" are addressed before moving on to "Components", "System Integration" and so on. The questionnaire prepared by the authors was applied through an online tool using Google Forms. The call to answer the questionnaire was sent by e-mail to the staff of the companies and by direct interviews with the directors, superintendents or managers, in this order, according to accessibility. From the answers informed by the managers, it was observed to what extent each company invested in the technological sector, i.e., in what degree of technological maturity is the respective company. Therefore, 04 (four) approaches to the analysis of the level of technological maturity were defined. The first is the analysis approach that considers the TRL Calculator work. The second approach was developed according to the NBR 16290 standard (ABNT, 2015). The third approach was developed by the authors that considers all completed activities and their respective TRL levels. Finally, the fourth and last approach, also developed by the author, calculates the percentage of completion of each TRL level by the evaluated companies.

TRL Calculator Approach: In this approach, the technology is considered mature at a given level if all tasks related to this level are completed. The percentage of each question was analyzed. If the percentage of an activity is equal or superior to 80% (tolerance), the task was considered as "sufficiently completed". This percentage is used in the TRL Calculator work as an estimate that the activity is close to completion (considering error margins of 10%) and that the results of the respective activity may be ready, waiting only for the formalization of the closing of the activity. Therefore, it is verified that all activities inherent to a TRL level have percentages equal to or higher than 80%. If this condition is met, this TRL level is considered achieved and the activities at the next level are checked until TRL level 9 is reached. This approach considers that a TRL level comprises all activities relevant to a moment of technological maturity. Therefore, it considers that a company can only go up to the TRL level if all the conditions of the previous level have been fully met. In this approach, the degree of maturity achieved by the technology will always be the smallest fully complete degree of scale. For example, technology "X" has all tasks as completed at TRL level 2, has some tasks completed at TRL level 3 (not all) and all tasks completed at TRL level 4. In these terms, we define that technology "X" meets the technological maturity of TRL level 2. Therefore, we can consider this approach is linear and can be compared to the cascade software development model, in which the process is seen as a constant forward flow (like a cascade) through the sequential phases.

NBR approach: The NBR approach is like the TRL Calculator approach in that it considers the minimum percentage of 80% to indicate when an activity is said to be completed. However, this approach differs from the previous one in that it does not require completion of all activities at the TRL level to consider this level achieved. According to NBR ISO 16290:2015, each TRL level has activities considered essential, which define the objective to be achieved at each level. Thus, in the NBR approach, the TRL level is said to have been achieved if all the activities considered essential are completed, i.e. they have a percentage of completion equal to or greater than 80%. In this case, the percentages of the other activities are not considered for the calculation. Considering the possibility of having complete TRL levels with incomplete previous levels, the degree of technological maturity has its level defined by the lowest TRL level with all essential activities completed. These essential activities were not differentiated from other activities at the time of application of the instrument, precisely to verify whether the respondents know the importance of these activities.

Weighted Approach: The Weighted approach was created by considering that each activity, regardless of which TRL level it belongs to, has importance in the technological maturity process. This approach invests weights in each TRL level, according to the defined metric scale. For example, activities at TRL level 1 have a weight of "1", activities at TRL level 2 have a weight of "2", and so on, up to activities at TRL level 9 (which have a weight of "9"). This is because the activities of the initial TRL levels are less significant than the activities of the more advanced TRL levels in terms of the increase in the degree of technological maturity. That is, the activities of higher TRL levels indicate that the technology already has some technological maturity, while the initial levels indicate that research is being developed and that the environment is being prepared for the next levels. It is important to emphasize that, in this approach, all the activities described at all levels are important and what differs are the weights that each one will have in the calculation of the technological maturity. The calculation of the degree of technological maturity is given by the following equation:

$$G_{mat} = \frac{1 * Med(tarefas\ TRL\ 1) + 2 * Med(tarefas\ TRL\ 2) + \cdots + 9 * Med(tarefas\ TRL\ 9)}{45}$$

Equation 1: Calculation of the degree of maturity (Weighted Approach): Where$Med$is the median function that returns the mean value of the set of completion percentages for all activities of a TRL level.That is, $tarefas\ TRL$ 1has the median of the percentages of all tasks pertinent to TRL level 1, and the same occurs with the other levels. Once the median is found, it is multiplied by the weight corresponding to the level. At the end, the calculation is divided by the sum of the weights of each level (1+2+3+...+9), totaling the value of 45, indicating that it is a weighted average of the listed activities. Unlike the TRL Calculator approach, any percentage of the activities is considered in the final calculation of the degree of technological maturity. It is worth noting that the higher the percentage of completion of activities, the higher the value of the degree of technological maturity. In addition, the more activities completed or partially completed at higher TRL levels, the higher the degree of technological maturity, which is relevant given that activities at higher TRL levels assume that the technology is at more advanced stages of development. The value of theG_{mat}needs to go through a mathematical correction. The value calculated according to Equation 1, in the case in which all activities were completed and the technology is at TRL level 9, indicates the value "10", a value that does not correspond to any TRL level, because there are only 9 levels according to the definition of the TRL metric used in this study. Thus, the value of the degree of real maturity is defined as:

$$C = (G_{mat} * 9)\ /10$$

Equation 2. Adjustment in the calculation of the degree of maturity (Weighted Approach)

This calculation is used to indicate the value of the degree equivalent to a scale with only 9 levels, instead of 10. This correction does not interfere in what is expected to be obtained in the results of Equation 1.

Percentage Approach: The latter approach, like the previous one, also considers all percentage rates of completion of all activities. However, this approach does not seek to calculate the degree of technological maturity and identify it among the TRL levels. This approach aims to verify how complete each TRL level is in each company. The percentage of completion in each level is calculated as follows: All percentages of completion of all activities in the level are added together and divided by the total completion value of all activities by 100%. For example, when analyzing a certain TRL level with 05 (five) activities, a company had the following conclusion results in activities of this level: 40%, 90%, 100%, 70% and 80%. The calculation according to the Percentage approach would remain:

(40% + 90% + 100% + 70% + 80%) / 500% = 76%

Therefore, the company would have completed 76% of this TRL level. This calculation would be performed for all TRL levels and, thus, the company would have the idea of completeness of each level for its company/technology. In this case, the 80% tolerance percentage is not considered, because it is sought to identify how much each level was completed and not if the level reached the minimum of completeness.

Data Analysis

The four approaches are calculated for each company and are compared with the vision that the company's manager has regarding the technology he or she uses.

Table 1. Managers' vision of their technological maturity

Companies	Response obtained	Corresponding TRL level
E1	A viabilidade do produtopodeserconsideradacomodemonstrada e o desempenho das funções críticas é verificado através de testes em ambiente relevante	TRL 5
E2	O produto foi bem testado e aprovado em ambiente operacional real, assegurando desempenho esperado pelo cliente.	TRL 9
E3	O produto foi bem testado e aprovado em ambiente operacional real, assegurando desempenho esperado pelo cliente.	TRL 9

The vision of the manager is captured in the question "*In your opinion, what is the stage of development (TRL - Technology Readiness Level) of your product in relation to marketing?"*

In the question above, the formal definitions of each TRL level were indicated, thus avoiding making the levels explicit by their scale numbers. In this way, the author tried to force the manager to evaluate each definition and verify which one best fits its technological business reality. Moreover, it is avoided that the manager tries to infer that the technology is at high TRL levels, without necessarily being the reality of the company. To make the result even more loyal, the formal definitions of the TRL levels are purposely and automatically shuffled by Google Forms, thus avoiding that the manager only chooses the last option as the answer, indicating a high TRL level. The comparative analysis of the manager's vision with the results obtained by the four approaches is necessary in order to assess the manager's level of knowledge in relation to technological maturity. The results obtained were analyzed using a quali-quantitative method using basic statistics, where it was observed, for each activity, the mean of the percentages of responses of the companies for that activity, the sample standard deviation, the normality zone and the coefficient of variation for that activity. From the analysis of the mean and standard deviation, it was possible to verify which are the activities with percentages closer to the mean, indicating that these activities are well defined for all companies and that the activity is a common practice (and may even be a taught activity in its incubation period). We also analyzed the normality zone, where it was possible to verify the probability of the activity in question being close to the percentage of 80%, defined in this work as the limit to consider an activity as completed, taking as an example the default threshold of the TRL Calculator 2.2 application by William L. Nolte, Brian C. Kennedy and Roger J. Driegiel Jr. (2003). The coefficient of variation, which shows the extent of variability in relation to the population mean, was applied to evaluate the results of the same response variable (i.e., an activity), allowing to quantify the accuracy of the surveys. The lower the coefficient, the higher the accuracy of the data. This calculation served for the reliability and accuracy of the data obtained. After calculating the degree of technological maturity, the three academic spin-offs were classified using a typology developed by the author, considering the metrics of the TRL levels:

Academic spin-off with test technology: when the spin-off is still in the process of research and development of the new technology to be used and performing the first experimental tests and proofs of concepts. These companies, when analyzed by the instrument, are classified between levels TRL 1 to TRL 3.

Academic spin-off with prototyped technology: this spin-off already has a formulated concept of the technology and the fidelity of the product coming from the technology is growing, demonstrating that the production of the product is viable. They are companies that already have functionalities/ components identified, being verified one by one, until generating a prototype that is tested in real environment. These spin-offs are classified between levels TRL 4 to TRL 6, when the instrument of this research is applied.

Academic spin-off with mature technology: these companies already have the product in the final stage of development or already completed, needing only to perform final tests, document the entire production process, validate and start production (on a small or large scale). It is a spin-off considered ready for the market and its classification, according to the questionnaire, is between levels TRL 7 to TRL 9.

RESULTS AND DISCUSSION

Initially, the visions that each manager has regarding the degree of technological maturity of the technology in which they invest were analyzed. As previously stated, the questionnaire did not indicate the TRL levels directly, but the formal definitions of these. In this way, we avoid that the respondent chooses by the number of the scale and, yes, by the definition in which its technology is most suitable. In the case of companies with more than one technology in production, respondents were asked to respond considering the most developed technology. This decision was made so that one could analyze the activities of all TRL levels, given that if a technology was chosen at an early stage, it would not have passed through most of the tasks indicated in the questionnaire and an analysis of all the tasks would be impossible. Therefore, we consider the best technological case for each company, that is, the technology that already produces (or is close to producing) a final product for the market. After a thorough analysis of the activities of each TRL level, it is possible to calculate the degree of technological maturity of the companies, following the four approaches mentioned above: the TRL Calculator approach, the NBR approach, the Weighted approach and, finally, the Percentage approach. The TRL Calculator approach considers as a TRL level achieved when the company effectively completed all activities related to that level, considering as finished the activity that has a percentage higher than 80% of finishing. It is noteworthy that this limit was defined by the author, considering the example of the TRL Calculator application in spreadsheet, considering the margin of error of 10%. The NBR approach considers as achieved TRL level when the company has effectively completed all activities considered essential for each level. This approach considers as completed the activity that has a percentage above 80%. The lowest TRL level with all essential activities completed is the TRL level indicated by this approach. It is important to highlight that all activities are important for this approach, but the essential activities are indispensable for each TRL level.

Table 2. Comparative Analysis of Maturity Ratings

Degree of Technological Maturity					
Companies	Manager's Vision	TRL Calculator Approach	NBR approach	Weighted Approach	Percentage Approach
E1	TRL 5	TRL 2	TRL 4	TRL 6	TRL 1: 99% TRL 2: 98% TRL 3: 100% TRL 4: 97% TRL 5: 89% TRL 6: 73% TRL 7: 60% TRL 8: 51% TRL 9: 38%
E2	TRL 9	TRL 9	TRL 9	TRL 9	TRL 1: 100% TRL 2: 100% TRL 3: 100% TRL 4: 100% TRL 5: 100% TRL 6: 100% TRL 7: 100% TRL 8: 100% TRL 9: 100%
E3	TRL 9	TRL 1	TRL 9	TRL 8	TRL 1: 89% TRL 2: 88% TRL 3: 87% TRL 4: 85% TRL 5: 87% TRL 6: 85% TRL 7: 88% TRL 8: 83% TRL 9: 86%

These define the scope of the technology that each TRL level intends to develop. The Weighted approach considers the percentages of each activity and assigns weights to each level, where weights increase in proportion to the increase in the TRL scale. TRL 1 activities have weight 1, while TRL 2 tasks have weight 2 and so on. These weights can be considered as a degree of importance that the levels have in relation to the increase in technological maturity. Therefore, the degree is calculated according to Equation 1. It is important to emphasize that all TRL levels are important for technological maturity. Indeed, it is impossible to mature a technology if it has not been extensively researched and/or continuously tested. However, in the field of technological development, activities at higher TRL levels can be considered more important than activities at lower levels because they effectively demonstrate the development of the technology, such as prototyping and testing in laboratory and real environments. The Percentage approach does not define a single degree of maturity. It informs the full percentage of all TRL levels for each company and assesses, more comprehensively than other approaches, how much is needed for each level to be complete. The following table shows the result of the comparative analysis of the degree of technological maturity that the manager perceives in his company, the degree achieved by it after completing the questionnaire according to the TRL Calculator approach, NBR approach, the Weighted approach and the degree of completeness of all levels, according to the Percentage approach. The Manager's view shown in the chart above is obtained between the initial questions in the questionnaire. When asked about the stage of development of the product in relation to commercialization, the respondent analyzes through a superior perspective which definition best fits the reality of its spin-off. The lack of indication of the TRL levels was deliberate at this time to subject the respondent to read the definitions and choose the most appropriate one.

By comparing the degree indicated by the manager with the degrees obtained through the four approaches mentioned, we can verify that the Weighted approach and the NBR approach are closest to the respondent's view. In fact, the TRL Calculator approach proved to be rather limited in the sense of calculating the degree of technological maturity. This is because a level must be obtained if, and only if, all the tasks related to that level are completed (the percentage of completion stipulated). Although limited to also requiring a minimum completeness of 80%, the NBR approach came closer to the manager's vision and to the company's reality because it required the minimum percentage only for the activities considered essential. It is interesting to note that the percentage of completion must be reasonable, and this is ineffective when it is very low. A percentage of 50% completion, for example, is not consistent with the reality that an activity is completed (in this case, the task was completed by half). In addition to approaches that seek to calculate a fixed maturity level value, the Percentage approach shows how complete the TRL levels are for each company. It is interesting to note that company E1 has high percentages of completeness up to a certain level (up to TRL level 6), where after this, the completeness of the levels tends to decrease up to 38% at TRL level 9. This is because this company has activities not yet completed from TRL level 6, which is in line with what the Weighted approach for this company stated. Another interesting factor is the scope of activities. In this work, we try to cover as many pertinent activities as possible for each level. However, even so, through the answers obtained, we can observe that some factors were not remembered such as, for example, "the perception of the target audience about the technology in the initial phase of development" at the TRL level that addresses the basic principles observed (TRL 1). Therefore, to really verify if a TRL level was complete using the TRL Calculator approach, one should observe if the scope of evaluation of each level is quite comprehensive. For the NBR, Weighted and Percentage approaches, the scope is important, but it is not essential for the calculations performed by them. Because the median of the percentages of a TRL level is calculated and is independent of the quantity of activities, the Weighted approach will always generate a middle value of the set of percentages of a level.

The Percentage approach calculates the completeness of each level and therefore the scope can be modified at will, but the completeness calculation will always remain the same. The NBR approach is not influenced by the scope because the activities considered essential are independent of the branch to be assessed. These activities are specific to the objective of each level, being important activities for any type of technology to be evaluated. Although the questionnaire was validated by 02 (two) professors in the Biotechnology area, even so, tasks pertinent to the area were identified that were not included in the questionnaire. The ideal scenario is that there would be more spin-off academic participants in the study so that there would be more contributions on the scope of this work or more validations of professionals in the Biotechnology sector. The TRL Calculator approach and the NBR approach also fail to consider the activities completed at levels above the level considered completed. In other words, if a company has all activities up to TRL level 3 ready, does not have all activities of TRL level 4 performed and has some activities of TRL level 5 performed, the level calculated by these approaches is TRL level 3, and all activities of TRL levels 4 and TRL 5 are neglected.

These approaches end up disregarding activities that the company has domain and that, perhaps, has concluded before performing tasks considered simpler (of lower levels). The knowledge to perform these activities above the level obtained proves that the developer company has a higher degree of technological expertise than calculated, and thus this knowledge cannot be underestimated in the calculation of technological maturity. The Weighted approach arises to repair the errors identified by the TRL Calculator and NBR approaches. The Weighted approach considers all percentages regardless of whether they are above or below the stipulated limit. In addition, it considers that the activities of the higher TRL levels have a greater weight in the calculation of technological maturity. This is because these tasks to be performed need knowledge acquired in previous levels and this knowledge shows that the company researched and executed processes, resulting in each element, process and/or documentation. Soon, the company gained knowledge about the use of technology and, therefore, the maturity of the company in relation to the science involved grew. Based on the following example: if a company has implemented a Training Plan for its product customers (activity TRL 9). To conduct the training, the company must have completed most of the documents relevant to the training (activity TRL 8).

These documents need to define in which environment the product will be used (TRL activities 6 and 7) and for the success of the training, the company must have tested all the functionalities of the product (TRL activities 5, 6, 7, 8). It is notable that a higher-level activity depends on the fulfillment of several other lower-level activities. Thus, this activity encompasses much more technological maturity to be complete than an initial market research activity, for example. For this reason, the weight of TRL activities grows according to the progress on the TRL scale. This approach avoids that a company that has a certain field of performance well developed (research vision, for example) and another poorly developed (market vision, for example) is evaluated according to the middle term between them, unlike the TRL Calculator approach, which evaluates through the union of all the fields of performance and ends up indicating the degree where all the fields of performance are fulfilled. This percentage multiplied by the respective weight of the TRL scale indicates the weight of that TRL level for the total technological maturity of the spin-off analyzed. In short, the Weighted approach is a weighted average of the mean values of the percentages of the activities in the questionnaire. The Percentage assessment, differently, analyzes the completion of all activities at all levels. From this comprehensive analysis, it is possible to identify how much each company has invested in and carried out the relevant procedures at each level. Regarding the statistical calculations performed (mean, sample standard deviation, normality zone and coefficient of variation), they ended up being underutilized due to the minimum sample size of the universe surveyed. According to the typologies indicated above and considering the application of the instrument of this work and the Weighted approach, we can infer that the companies studied in this research are classified according to Table 3.

Table 3. Classification of the companies studied according to the TRL typology

Company	TRL Level (Weighted Approach)	Category
Company E1	TRL 6	Academic spin-off with prototyped technology
Company E2	TRL 9	Academic spin-off with mature technology
Company E3	TRL 8	Academic spin-off with mature technology

The instrument in the form of a questionnaire developed in this work provided the managers of the companies with a significant amount of information on which activities should be performed for the good progress of product development in relation to the technology analyzed. From the analysis of the tasks to be fulfilled, the person responsible for the company can define the overall risk of product development. This is because he can measure the maturity of the technology and, in general, a mature technology presents less implementation risks than immature technology. In these terms, the instrument proved to be a useful tool in a risk management program. The activities of the questionnaire and their respective percentages of completeness can help the manager in monitoring technological progress, in order to monitor the progress of what is being done and what needs to be done. This information can be used to discuss the progress of activities with the team and, if necessary, require greater attention to important activities that have not yet been completed and/or are in arrears. Thus, the instrument can be used to improve the organizational performance of the academic spin-off, since it can help define processes and refine the management of the company. Despite the good grades, it was observed that some areas were partially or not included in the incubation process applied to them, given their low percentages. Examples of this are: (i) knowledge about product commercialization; (ii) development of the technology requirements document through conversation with customers; (iii) plan of production tests in scale (production scalability). Another point observed after this work is that this type of technological maturity assessment requires that the completed activities are proven. The proofs serve to prevent the companies from deliberately

completing the questionnaire, claiming that the activities were concluded without being. Through the supporting documents, the questionnaire becomes a more efficient and guaranteed evaluator, being able to offer concise information to potential angel investors who are looking for biotechnology companies to invest in. This technology assessment tool is not exclusively applicable to the biotechnology industry. By making the necessary changes consistent with the specific branch, the questionnaire can be used to evaluate the technology of other areas such as the medical area, information technology, security, among others. Logically, for the use of the questionnaire, it is necessary to have a technology to be evaluated. Regarding the approaches used to measure the TRL level of companies, it can be concluded that the Weighted Approach, created by the author, was the one that best identified the TRL levels of companies according to their realities. While the TRL Calculator Approach indicated that a company was at a low TRL level by not completing all activities at that level, the Weighted Approach considered all activities at all levels, considering that activities at higher levels are more relevant to technological maturity. During this research, some obstacles were identified that hindered the progress of the work. Initially, it was thought to work with several academic spin-offs - state, other regions and even international. Contact was made with several of these companies in the biotechnology industry, however, because of the content of the research to question the progress of technological research and the fear of industrial espionage, the companies did not participate in the research, alleging the fear indicated, lack of interest and even not answering anything.
As a result, the sample of companies assessed was small and did not provide a better statistical analysis and comparative analysis between companies from different regions.

Conclusion

The work was able to evaluate the technological maturity of three academic biotechnology spin-offs incubated by INCUBAUECE. This evaluation was performed from 04 (four) different approaches: the TRL Calculator approach, the NBR approach, the Weighted approach and the Percentage approach, the latter two being new proposals for the analysis approach. All four approaches used the TRL scale, each with its own specificities. These specificities showed which approach is best suited for a commercial application of this assessment. In this aspect, the Weighted approach proved to be the most appropriate. The UECE provided infrastructure and personnel, in addition to other services, to facilitate the implementation and development of the three companies. However, it is worth noting that the guidance given to the companies refers to business development, thus disregarding the technological development, always leaving it to the company itself. Considering the results obtained in the essential activities according to the Brazilian Standard 16290:2015, the basics of each TRL level were explained by INCUBAUECE, only having to refine their work, improving the instructions of other activities that the companies demonstrate difficulties. Thus, the new companies that will be incubated by the same process will have a better implementation and development performance.

REFERENCES

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 16290: Sistemas espaciais - definição dos níveis de maturidade da tecnologia (TRL) e de seus critérios de avaliação. *Rio de Janeiro*: ABNT, 2015.

ISO. International Organization for Standardization. ISO 16290:2013 - Space systems - Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment, Suíça, 2013. Disponível em: <https://www.iso.org/obp/ui/#iso:std:iso:16290:ed-1:v1:en>. Acessoem: 7 set. 2017.

MANKINS, J. C. Technology readiness levels: a white paper. 6 abr. 1995. Disponível em: <http://www. artemisinnovation.com/images/TRL_White_Paper_2004-Edited.pdf> Acesso em: 19 abr 2017.

NOLTE, W. L.; KENNEDY, B. C.; DZIEGIEL JR., R. J. Technology readiness level calculator. air force research laboratory.NDIA Systems Engineering Conference. 20 out 2003. Disponível em: https://ndiastorage.blob.core. usgovcloudapi.net/ndia/2003/systems/nolte2.pdf>. Acesso em: 30 nov 2017.

PEDROSI FILHO, G. Universidade empreendedora: criando riquezas através de spin-off acadêmica. Núcleo de Inovação Tecnológica, Universidade Federal de Roraima, 10 set. 2014. Disponível em: <http://ufrr.br/nit/index.php?option=com_content&view=article&id=93:universidade-empreendedora-criando-riquezas-atraves-de-spin-off-academico&catid=2&Itemid=102>. Acesso em: 25 set. 2017.

SANTOS, D. A. dos; TEIXEIRA, R. M. O processo de spin-off acadêmica: estudo de casos múltiplos de empresas incubadas da UFS. RAI – Revista de Administração e Inovação, São Paulo, v.9, n.1, p.31-50, jan. /mar. 2012. Disponível em: http://www.revistas.usp.br/rai/ article/view/79249/83320> Acesso em: 5 jan. 2018.

SHANE, S. Academic entrepreneurship: university spinoffs and wealth creation. Cheltenham: Edward Elgar, 20

****