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Research Article

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Methodology for assessing laser-based equipment

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Abstract: Methodologies for the assessment of technology's maturity are widely used in industry and research. Probably the best known are technology readiness levels (TRLs), initially pioneered by the National Aeronautics and Space Administration (NASA). At the beginning, only descriptively defined TRLs existed, but over time, automated assessment techniques in the form of questionnaires emerged in order to determine TRLs. Originally TRLs targeted equipment for space applications, but the demands on industrial relevant equipment are partly different in terms of, for example, overall costs, product quantities, or the presence of competitors. Therefore, we present a commonly valid assessment methodology with the aim of assessing laser-based equipment for industrial use, in general. The assessment is carried out with the help of a questionnaire, which allows for a user-friendly and easy accessible way to monitor the progress from the lab-proven state to the application-ready product throughout the complete development period. The assessment result is presented in a multidimensional metric in order to reveal the current specific strengths and weaknesses of the equipment development process, which can be used to direct the remaining development process of the equipment in the right direction.

Keywords: decision making; laser-based equipment; management software; technology assessment; technology management; technology readiness level (TRL).

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1 Introduction

The development of methodologies for the assessment of technology's maturity is an ongoing task in the 21st century due to the increasing complexity and integration level of technological products [1]. The US Government Accountability Office (GAO) stated that maturing new technology before it is included in a product is perhaps the most determinant of the success of the eventual product [2]. In order to overcome cost overruns, schedule slips, and performance problems, different qualitative maturity assessment techniques to measure maturity and readiness of technology and its manufacturability were developed. These qualitative techniques are, for example, technology readiness level (TRL) [3, 4], integration readiness level (IRL) [5], system readiness level (SRL) [6, 7], manufacturing readiness level (MRL) [8], and technology readiness transfer level (TRRL) [9].

TRL was initially pioneered by the National Aeronautics and Space Administration (NASA) in the 1980s as a methodology to assess the maturity and risk of space technology [10]. TRLs measure the degree of maturity of evolving technologies as, for example, of devices, components, software, and work processes during their development and allow for a consistent comparison of maturity between different equipment. TRLs range from 1, where basic principles are observed and reported, to 9, which corresponds to an actual technology proven system through a successful deployment in an operational setting. The TRL methodology was incorporated into the NASA Management Instructions (NMI) as systematic approach of evolving technologies. Later, these metrics were adopted by the US Department of Defense, the European Space Agency, and several other organizations and adapted to their needs [11]. Currently, the TRLs have been widely adopted by the industry and are used by engineers and project managers to make critical decisions about the maturity of technology [12]. However, this metrics is considered deficient [13] because it was never intended to assess, for example, the integration of a given technology with another within large and complex systems [5]. Therefore, other metrics have been developed to cover all aspects of technology readiness as integration.

As the other qualitative maturity assessment techniques MRL, IRL, TRRL, etc., the levels are descriptively defined, making them subjective and simplifying certain facets of maturity and readiness. The description of each tier can be interpreted in different ways leading to inaccurate assessment. A major drawback of the qualitative techniques is the difficulty to assess complex systems consisting of multiple technologies that interact with each other. As the result of the TRL analysis is unidimensional, it cannot cover all aspects in equal measure [14]. In addition to the subjective assessment and the lack in definition of terminology, it is a serious limitation of TRLs that the maturity in one application can be immature in another. Therefore, it is required to assess the technology maturity in relation to the specific requirements of the system [15].

Because of the demand of an improved assessment methodology, quantitative methods have been developed using mathematical models in order to calculate the risk involved in the product development. One of these models is called ITAM (integrated technology analysis methodology) [16], which calculates the 'system challenge'. A similar model called TRRA (technology readiness and risk assessment) [17] combines TRLs, a standard risk matrix, the difficulty to move technologies between TRLs, and the technology need value to map the probability of failure. In comparison to qualitative techniques, the quantitative techniques provide more objectiveness, are more precise, and integrate multiple system metrics. Nevertheless, the methods can be too complex and difficult to be applied by the user. The techniques are less flexible to different programs and susceptible to mathematical miscalculations [18, 19].

In addition to quantitative and qualitative assessment techniques, a third category, referred to as automated techniques, was proposed in Ref. [13]. These methods use a tool, which performs a quantitative analysis in the background in order to calculate a result indicating the maturity of the assessed technology. The user completes a comprehensive questionnaire, which can cover different relevant fields and allows for the assessment of topics, which cannot be simply described by numerical values. One implementation was pioneered by the Air Force Research Laboratory (AFRL) using a Microsoft Excel-based tool, which computes the TRL based on a completed questionnaire delivering a graphical output [20, 21]. The calculator was also adapted to calculate the MRL value. These automated techniques share many attributes of the qualitative and quantitative techniques and are especially more objective, user-friendly, and allow for a repeatable consistent comparison of different technologies at consecutive points in time. Nevertheless, these techniques mainly depend on the quality of the questions. The questions have to be clearly formulated avoiding misinterpretation because, otherwise, this would result in a wrong assessment. In addition, the methodologies have to be user-friendly and easy to understand and use in order to encourage and facilitate their application. However, the questions of the AFRL TRL calculator are specifically for space and defense system technologies, a fact that could hamper the use in the industry (in particular, at small- and medium-sized enterprises) [22] due to complicated and abstract wording of the questions and potentially missing industrial relevant categories such as economical aspects. Other metrics as SRLs are currently being extensively discussed because their use may distort, rather than improve, the decision-making process [18]. In conclusion, the development of commonly valid methodologies for assessing technology's maturity and readiness is a key point for all kinds of industry and economy, in general.

The European-funded project LASHARE [23] focuses on the assessment and development of laser-based equipment from lab-proven demonstrators to market ready products for industrial environments. Part of the LASHARE project is to provide a robust framework for the assessment of the product development process of laser-based equipment and related technologies. This covers from end-to-end the entire value chain for the technology components, such as, e.g. the laser system itself, customized equipment for a given manufacturing application, beam analysis equipment, laser heads, sensors for laser processing, etc. It also addresses improvements related to quality, speed, flexibility, and resource efficiency of laser-based manufacturing and processing with the aim to accelerate and ease the use of the equipment in real applications.

Because of the diversity of the applications and the number of available solutions, it is difficult to compare different equipment and measure the improvements that can be achieved and their cost-benefit, in general. Each technical solution as an isolated component that can, for example, be evaluated against performance figures such as laser power, energy distribution, and beam quality. This, however, does not yet describe the benefit of the equipment in the production chain. In order to keep competitive advantages or to provide advanced solutions, it is required to establish assessment criteria and corresponding metrics, which allow end users to estimate the overall investment required and the benefit associated with the laser-based equipment to be employed. Such evaluation criteria assist suppliers to characterize their equipment in terms of the development process and to establish more confidence for potential investors. Establishing these criteria within the assessment framework assists suppliers and users in identifying requirements for future development based on an objective set of information. By using this standardized method, technology maturity can be judged providing a significant amount of information about the overall product development risk. This is especially interesting for small- and medium-sized enterprises, which potentially do not have a standardized product development process in house.

Within the LASHARE project, a set of 14 laser-based equipment were assessed, which fulfilled the prerequisites of being not commercially available or already prototyped, having clearly identified industrial users and providing leverage for the manufacturing equipment market. In each laser equipment assessment (LEA), suppliers in the form of small- and medium-sized enterprises work together with research partners (e.g. research institutes) and end users. The LEAs benchmark the equipment in its current state and enable a reliable classification and evaluation of the developed equipment. In order to perform a detailed assessment of the laser-based equipment, an automated technique in the form of a Microsoft Excel-based comprehensive questionnaire is proposed. The AFRL questionnaire developed by the NASA [20, 21] considers aspects as maturity, readiness, reliability, and robustness, but for the LEAs, further categories such as manufacturability and economic aspects are of major significance. Compared to space applications, as originally targeted by the TRLs, the requirements for industrial relevant equipment are partly different in terms of, for example, overall costs, product quantities, or the presence of competitors. Furthermore, TRLs give no information about risks involved in the development or the potential of the equipment to reach higher TRLs. There may be significant risks in achieving the next level of maturity even when a program is maturing on schedule [8].

In this paper, we present an automated assessment technique based on a questionnaire with a reasonable set of questions, which are grouped according to relevant categories in order to deliver a versatile assessment scheme, which is primarily focused on laser-based equipment. The aim is to provide a user-friendly and easily accessible methodology to monitor the development of the maturing product and to allow for a repeatable and consistent comparison of it at different development stages. The assessment is multidimensional, which means that each category is rated for itself to identify specific strengths and weaknesses of the equipment at the current state of development. By doing the assessment, the user learns more about the developed system, which allows him to initiate proper development steps.

The presented assessment results were obtained in the framework of LASHARE and correspond to the status of the LEAs at the beginning of the project and the end of the project for the LEAs. In addition to the multidimensional metric, a unidimensional assessment scheme in the form of a single number is calculated and allows for an overall rating of each LEA. However, the major achievement is, without doubt, the multidimensional metric, as unidimensional metrics provide only a small part of the relevant information. This approach is developed in terms of general means applicable to the assessments in LASHARE and beyond. We think that with the presented questionnaire, we will encourage more suppliers to use this type of assessment tool, especially in small- and medium sized enterprises. This questionnaire is designed for the assessment of laser-based equipment, but in principle, it is applicable to any other field.

2 Automated assessment methodology

A questionnaire offers a flexible, robust, user-friendly, and comparable way to assess intrinsically different equipment at different points in time. Because of the high maturity of the TRL calculator [20] developed by the AFRL, this tool is used as the basis for the presented questionnaire. In contrast to the questions in Ref. [20], which are categorized according to their TRL, the questions in the presented questionnaire are categorized according to different topics (categories), and the questions cover the transition from a demonstrator (TRL 4) to a product (TRL $\geq$ 7). Of major importance for the questionnaire are appropriate categorization and the high-quality level of the questions. Relevant categories were deduced from common TRL calculators as Ref. [20] such that all important aspects as maturity, reliability, and robustness are covered by the questionnaire. In addition, industrial-relevant categories covering project management, quality assurance, manufacturability, and commercial aspects were considered and adapted to their special needs. Therefore, the questionnaire is categorized as shown in Table 1.

As the assessment should be applicable to a broad variety of laser-based equipment, the questionnaire contains the flexibility to consider the specific demands of each equipment type. Therefore, an equipment-specific assessment section was implemented in the questionnaire referring to individual improvements, comparisons

Table 1: Categories and description in keywords.

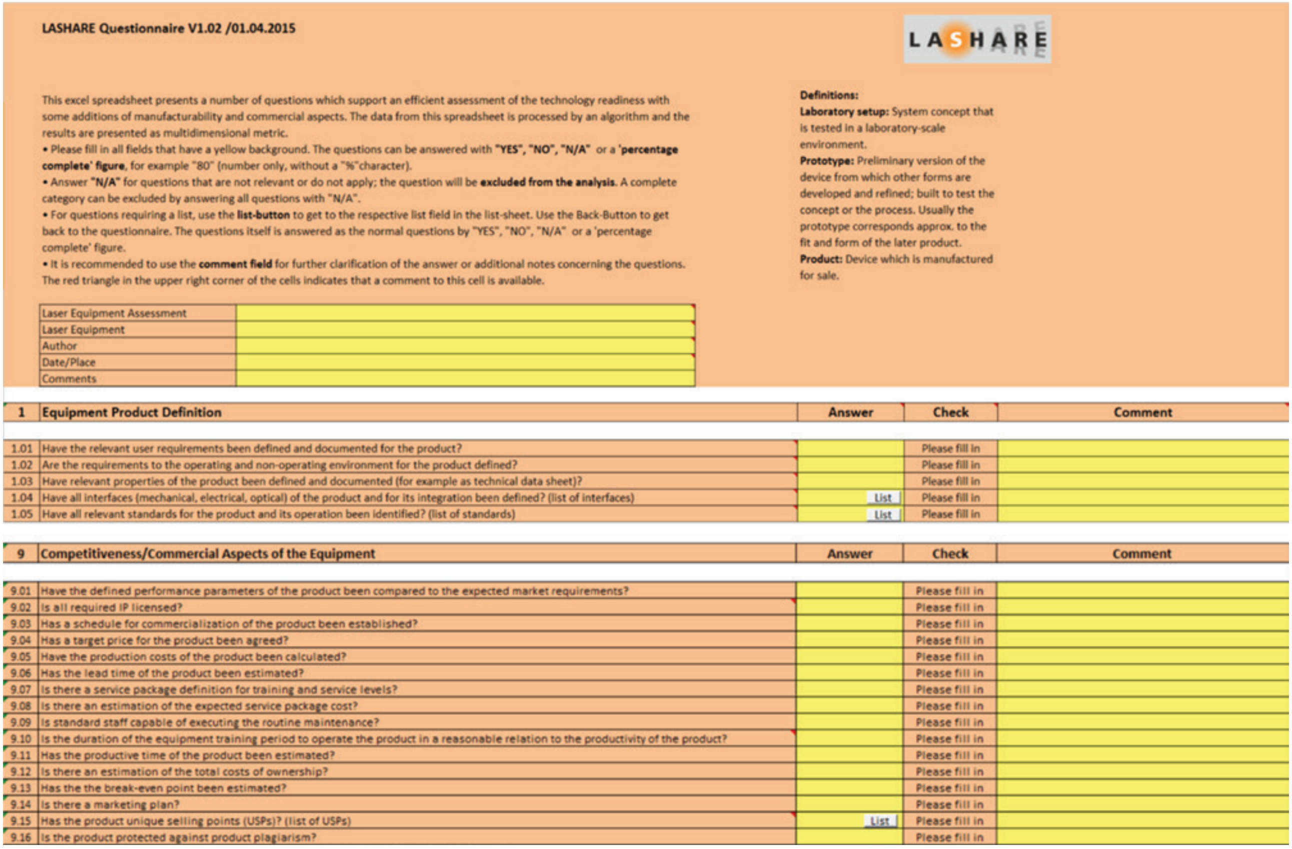
Category	Description in keywords
Equipment product definition	Definition of user requirements and the operating environment, availability of the technical data sheet, definition of interfaces and standards
Technical maturity	Demonstration of enabling technologies and critical components, verification of relevant functionalities and the working principle, operation of the prototype in laboratory and industrial environment, documentation
Reliability	Definition and verification of mean time between failure and mean time to maintenance in laboratory and industrial environment, monitoring of operating variables
Robustness	Definition and verification of the storage and operating temperature and humidity range, testing of vibration level, impact of external influences (e.g. contamination)
Software	Definition of software development, implementation of all intended functionalities, demonstration in the prototype, testing of all interfaces, definition of service strategy, security, documentation
Project management	Establishing of project management process, definition of a work breakdown structure and schedule, establishing of cost plan, allocation of resources and risk management
Quality assurance	Application of a quality management system, detection of performance deviations, implementation of design optimizations, definition of part lists, (second source) suppliers, incoming/outcoming inspection procedure, documentation, assembly/manufacturing process, certification, user manual, and transport packaging
Manufacturability	Availability of internal and external components, demonstration of the manufacturing process chain and the assembly process, allocation of resources for the planned production volume
Competitiveness/ commercial aspects	Comparison to the expected market requirements, licensing of IP, Schedule for commercialization, definition of price target, production costs, lead time, service package, productive time, break-even point, marketing plan, unique selling points, and plagiarism protection
Equipment-specific assessment	Planned improvements for future development, comparison to conventional equipment, essential performance parameters

to conventional equipment, and essential performance parameters of each LEA. This section is purely informative, and no rating is calculated. The questionnaire is designed for technical product development, in general, as can be seen in the keywords shown in Table 1, which are universally valid.

The questionnaire contains approximately 90 questions, which have to be answered by the user. In Figure 1, a snapshot of the questionnaire is depicted, showing the yellow user-editable fields for the identification of the equipment, the answers, and the comments. Answers can be given by simply typing 'Yes' or 'No' or a percentage value (e.g. 80), which represents the degree of fulfillment of the question. In addition, it is possible to exclude a question or a complete category from the analysis (e.g. software, if it is not applicable to the equipment to assess). A checkbox is used to indicate to the user if the question has to be filled out and if the answer fits to the input format. As shown in Figure 1, some answer boxes have so-called list-buttons, which redirect to a list sheet. The intention is to allow for a printer-friendly summary of all important interfaces, standards, and unique selling points of the equipment. In principle, the questions with a list button are answered in the same way as normal questions, but the corresponding standards, etc., are to be specified in the list sheet. The list sheet is purely informative, and no rating is calculated based on the input.

Based on the user input, a quantitative analysis is performed in the background in order to calculate the assessment result. In order to perform the analysis, all answers are transformed into values ranging from 0 to 1. The rating of each category is then calculated as the arithmetic mean of all questions within the category. A rating of 0 is low, and a rating of 1 is high. Furthermore, it is possible to weight each question in the automated analysis in order to increase or lower the impact of a question within the calculation of each category rating. However, for the presented results, all questions were equally weighted. The project partners of the 14 LEAs suggested weightings for each question according to their relevance within the questionnaire. The suggested weightings from the project partners show that all questions are of high relevance for the questionnaire. The ratings are used for the multidimensional illustration in the form of a radar chart, which allows for identifying specific strengths and weaknesses of the equipment. In addition, a collapsing weighted criterion to a single number for classification in a unidimensional assessment scheme is determined as the overall rating by calculating the arithmetic mean of all the categories.

In summary, the presented questionnaire provides a simple and fast method to measure the development status and to identify the highly and poorly developed parts of the assessed equipment. The completed questionnaire offers



LASHARE Questionnaire V1.02 /01.04.2015

LASHARE

This excel spreadsheet presents a number of questions which support an efficient assessment of the technology readiness with some additions of manufacturability and commercial aspects. The data from this spreadsheet is processed by an algorithm and the results are presented as multidimensional metric.

• Please fill in all fields that have a yellow background. The questions can be answered with **"YES", "NO", "N/A"** or a '**percentage complete' figure**, for example "80" (number only, without a "%"character).

• Answer **"N/A"** for questions that are not relevant or do not apply; the question will be **excluded from the analysis**. A complete category can be excluded by answering all questions with "N/A".

• For questions requiring a list, use the **list-button** to get to the respective list field in the list-sheet. Use the Back-Button to get back to the questionnaire. The questions itself is answered as the normal questions by "YES", "NO", "N/A" or a 'percentage complete' figure.

• It is recommended to use the **comment field** for further clarification of the answer or additional notes concerning the questions. The red triangle in the upper right corner of the cells indicates that a comment to this cell is available.

Definitions:
Laboratory setup: System concept that is tested in a laboratory-scale environment.
Prototype: Preliminary version of the device from which other forms are developed and refined; built to test the concept or the process. Usually the prototype corresponds approx. to the fit and form of the later product.
Product: Device which is manufactured for sale.

Laser Equipment Assessment	
Laser Equipment	
Author	
Date/Place	
Comments	

1	Equipment Product Definition	Answer	Check	Comment
1.01	Have the relevant user requirements been defined and documented for the product?		Please fill in	
1.02	Are the requirements to the operating and non-operating environment for the product defined?		Please fill in	
1.03	Have relevant properties of the product been defined and documented (for example as technical data sheet)?		Please fill in	
1.04	Have all interfaces (mechanical, electrical, optical) of the product and for its integration been defined? (list of interfaces)	List	Please fill in	
1.05	Have all relevant standards for the product and its operation been identified? (list of standards)	List	Please fill in	

9	Competitiveness/Commercial Aspects of the Equipment	Answer	Check	Comment
9.01	Have the defined performance parameters of the product been compared to the expected market requirements?		Please fill in	
9.02	Is all required IP licensed?		Please fill in	
9.03	Has a schedule for commercialization of the product been established?		Please fill in	
9.04	Has a target price for the product been agreed?		Please fill in	
9.05	Have the production costs of the product been calculated?		Please fill in	
9.06	Has the lead time of the product been estimated?		Please fill in	
9.07	Is there a service package definition for training and service levels?		Please fill in	
9.08	Is there an estimation of the expected service package cost?		Please fill in	
9.09	Is standard staff capable of executing the routine maintenance?		Please fill in	
9.10	Is the duration of the equipment training period to operate the product in a reasonable relation to the productivity of the product?		Please fill in	
9.11	Has the productive time of the product been estimated?		Please fill in	
9.12	Is there an estimation of the total costs of ownership?		Please fill in	
9.13	Has the the break-even point been estimated?		Please fill in	
9.14	Is there a marketing plan?		Please fill in	
9.15	Has the product unique selling points (USPs)? (list of USPs)	List	Please fill in	
9.16	Is the product protected against product plagiarism?		Please fill in	

Figure 1: Snapshot of the questionnaire showing the header and two sections.

the basis for discussing the development of the equipment with customers, engineers, and project managers. The improvement of poorly developed categories during the development process leads to a substantial increase in the general maturity of the equipment. By consecutive assessment, in time, it is possible to monitor the progress during the development process and provide a standardized, repeatable process for evaluating the maturity.

3 Assessment of laser-based equipment

In the framework of LASHARE, each of the 14 LEAs was assessed with the help of the questionnaire at the beginning of the development stage. The finished LEAs were assessed at the end of their subproject in LASHARE in order to monitor the progress. The typical duration of a LEA was in the order of 20 months. Figure 2 shows the results of one assessment in the form of a radar chart at the beginning and the end of the project. The multidimensional assessment reveals that at the beginning of

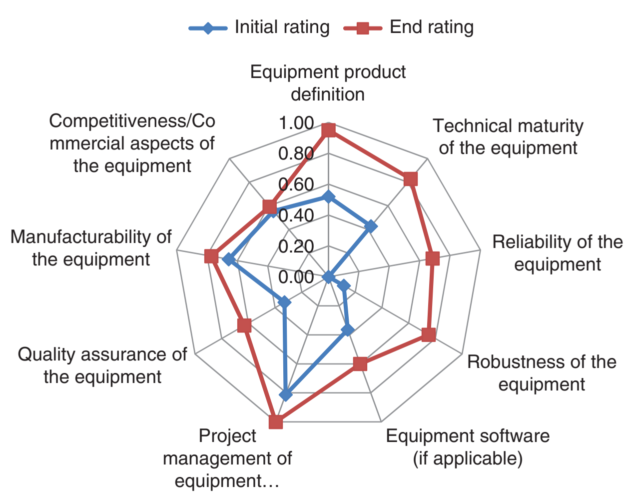


Figure 2: Multidimensional result of an assessed specific equipment at the beginning and the end of the LEA project.

the project categories, such as, for example, technical maturity, reliability, robustness, quality assurance, and the commercial aspects of the assessed equipment, are significantly weaker developed than the remaining categories. An in-depth analysis of the answered questions and the comments shows that for the presented equipment in terms of reliability, the mean time between failures was not defined and not verified. In addition, a prototype has not been operated in an industrial environment, which results in low maturity rating. With respect to the robustness of the equipment, the temperature and humidity range have not been verified and documented. It should be mentioned that, in the scope of the project, the transition from a laboratory prototype (TRL 4) to an industry-verified prototype (TRL ≥ 7) is covered. The low quality assurance rating is mainly due to the fact that the product is not embedded in an in-house quality management system, and inspection procedures for incoming and outgoing parts have not been defined yet. With regard to the commercial aspects and the product definition, it should be mentioned that typically, the specifications of the later product are well defined at this initial development stage. However, the commercial aspects in terms of market demand and competitiveness are unclear at the beginning of the development stage, which results in a potentially high risk that the prototype supplier is possibly not fully aware of.

This means that the further development of the equipment should emphasize on the achievement of these requirements, namely, to operate an appropriate prototype in an industrial environment, to reach the defined mean time between failure, to achieve a stable operation in a specified temperature and humidity range, to apply a quality management system, and to clarify the commercial impact of the product. However, the remaining categories seem to be already highly developed and should not be primarily addressed in the development process.

A comparison between the initial and end rating reveals that all the categories were improved during the LEA project duration. All poorly developed categories were significantly improved by addressing the previously mentioned topics, except for the commercial aspects of the equipment. The low commercial rating is mainly due to the lack of a long-term marketing and service plan. In general, the initial maturity of the presented equipment is relatively high with an overall rating of 0.43. At the end of the project, the rating has increased to a value of 0.83; however, the multidimensional analysis highlights that future development should focus on improving certain categories of the equipment such as the commercial aspects and the quality assurance. In conclusion, the questionnaire is suitable for monitoring the progress in each LEA from the project beginning to the project ending.

This is only one of the 14 obtained assessment results, which is representatively discussed. Other LEAs are, in part, poorly developed and require improvement in several categories, which is discussed in general means in the following section.

4 General assessment results

The discussion of one representative LEA demonstrates that the presented questionnaire allows for the identification of current weaknesses and for the deduction of further development recommendations as shown in the last section. However, in the following, some general assessment results are discussed, which were obtained from the analysis of all 14 LEAs. In Figure 3, a statistical evaluation of all assessments is depicted, showing the mean rating of all LEAs at the beginning of the project for each category, whereby the error bars indicate the standard deviation.

It should be mentioned that all LEAs were assessed at the beginning of the LASHARE project and that the initial development status of each equipment is different. The highest mean rating of a category is in the order of 0.75, and the lowest is in the order of 0.3. The category with the highest rating is the 'equipment product definition', which covers topics such as target specifications of the equipment that are either discussed in collaboration with the end user or the supplier has technically chosen, typically at the actual beginning of development. Therefore, this

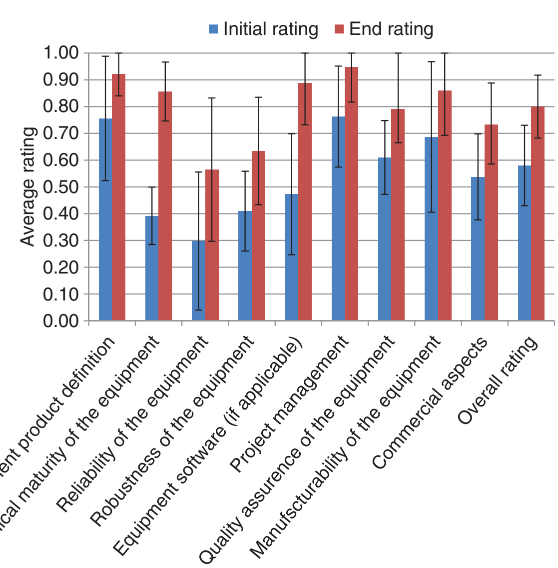


Figure 3: Progress of LEAs – average initial and end rating of categories for 13 finished LEAs.

category should be higher rated in most cases. Categories such as 'software', 'project management', 'quality assurance', 'manufacturability', and 'competitiveness/commercial aspects' have also ratings above 0.5 in the range of between 0.6 and 0.7 and are relatively highly developed. This is probably due to the fact that for the development of the assessed equipment, already existing in-house infrastructure and product development process can be used to some extent, and probably, similar products have already been developed or are currently under development. The lowest-ranked category is 'reliability', whereby categories such as 'technical maturity' and 'robustness' are below 0.5 as well. The general trend throughout all LEAs is that mostly categories that are covered by TRL-related categories are weaker developed than categories related to manufacturability and economic aspects. This is reasonable, as all LEAs are at the beginning of the development and are neither commercialized nor prototyped for an industrial environment. It is one of the major aims of LASHARE to improve these categories and close the gap between research leading to laboratory prototypes and a commercial product. An in-depth look into the answered questions can reveal the individual reason for the low rating and gives a hint for the required development steps.

However, the presented data has to be considered carefully, as the deviation from the mean rating is high in the order of 0.2 for all categories. Furthermore, it should be considered that LEAs are starting from varying equipment maturity status so that the average rating is prone to scattering. Furthermore, each questionnaire was filled out by a different person, which may result in possible deviations as each user may interpret each question slightly differently. Throughout the LEAs, the development status in each category can be very different. Nevertheless, the categories 'equipment product definition' and 'project management' seem to be uniformly highly rated by all LEAs.

In addition to answering the questions, the project partners of the 14 LEAs were asked to weight each question according to their relevance within the questionnaire with a value between 0 and 1. The results show that the lowest average value of the weighting was 0.75, which means that all questions are of high relevance for the questionnaire. In order to consider the fact that some questions cannot be applied reasonably to each LEA, the possibility to exclude questions and categories from the analysis is implemented in the questionnaire. The obtained averaged weightings were used to evaluate the impact on the final result. However, the consideration of the obtained weighting on the one-dimensional assessment scheme was negligible (±0.01 in overall rating) and, therefore, not applied in the statistical evaluation presented here.

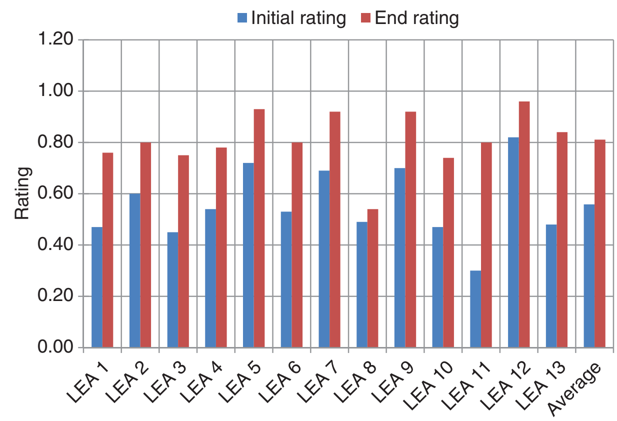


Figure 4: Comparison between LEAs – initial and end rating of finished LEAs.

In the current project run time, 13 LEAs finished whose results were evaluated to analyze the overall progress in the LEAs. The average rating in each category at the LEA project beginning and the project end are shown in Figure 3 for the finished LEAs, whereby the error bars indicate the standard deviation. The results are similar to the presented results for one LEA in Figure 2. All categories have improved during the project run time so that the averaged overall rating is increased by 0.22. In addition, the results also indicate that the lower the initial rating of a category, the higher the improvement during the development. This applies especially to the initially weaker developed categories such as 'reliability', 'technical maturity', 'robustness', and 'software', which are primarily in the scope of LASHARE. Although the presented LEAs have finished, they did not reach a maximal rating of 1. In order to identify the reason for that, an in-depth look into the questions is necessary.

A comparison between the finished LEAs as shown in Figure 4 demonstrates that all LEAs have improved their maturity. An exception is represented by LEA 8 in which problems in technical feasibility occurred. The rating is approximately the same after the end of the project. This means that the questionnaire works fine and is able to detect this stagnation. In general, it can be noted that the lower the initial rating, the higher the increment throughout the project run time. This is typical for product development cycles where major costs and efforts occur toward the end of the project.

5 Conclusions

We presented a commonly valid assessment methodology in order to assess the product development process of laser-based equipment, in general. In principle, the questionnaire can be used for technical product development in non-laser areas. A questionnaire, which covered approximately 90 questions that were grouped in 10 categories including TRL and economic relevant categories, was developed. The analysis routine is capable of performing a multidimensional analysis in order to identify specific strengths and weaknesses of the assessed equipment. It offers the basis for discussions between customers, engineers, and project managers and gives hints for improvable aspects of the product development process. It is then possible to address explicitly weak points and to take countermeasures just at the beginning of the project. The weaknesses can be identified not only on the basis of each individual question but also on the basis of the categories. In addition, the questionnaire works like a checklist to ensure that no aspect of the product development process is forgotten.

A concrete assessment result obtained in the framework of the European-funded project LASHARE is discussed, and the overall results gathered from the assessment of a laboratory prototype developed toward an industrial proven prototype are analyzed. Therefore, the presented questionnaire provides a user-friendly and easy accessible way to reliably monitor the development process from the lab-proven state to the later product.

Further research will be done to consecutively extend the scope in the field of laser-based equipment. As in the framework of LASHARE only 14 LEAs were evaluated, there is still room for improvement. The questionnaire will be used in future LEAs and is currently being integrated in some of the small- and medium-sized enterprises participating within LASHARE. This will give further feedback to continuously improve the questionnaire. In addition, the impact of the person in charge of doing the assessment will be investigated in the future.

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