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Integrating AM into existing companies - selection of existing parts for increase of acceptance

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Abstract

In many branches in the design engineer department, product designs are just variations of existing parts. To bring the additive manufacturing technology closer to the Designer, it is necessary to show them which of their existing, conventionally manufactured parts can be produced with this technology. A part selection methodology supports designers in the decision whether a part is suitable for additive manufacturing or not. Due to the potential of the technology, which was especially seen in the aerospace industries, many criteria of the methodology were initially adapted for this industry. Furthermore the methodology is based on a quantified weighting system, which comes to a certain subjectivity. For future use, a development towards a less subjective methodology should be accomplished. Through a more detailed adaption for individual industries and a simplification of the input mode, the objectivity of the criteria can be increased. Likewise, the input time can be reduced by simplifying the questioning. A more efficient part selection will be achieved by a better weighting system.
In the BMBF project "OptiAMix" this methodology is supposed to be further developed for highly different branches. By a better weighting system, the part selection will be more efficient. Therefore, the willingness for the use of the improved selection and for the additive manufacturing technology will be increased.

Introduction

Since additive manufacturing (AM) became suitable for direct manufacturing of products, the potentials of the technology are presented often. First one is the mass customization which gives customers the opportunity to get an individual product for costs which otherwise would only be possible for unitary mass production products. Also possible through AM is the integration of different elements and functions of an assembly in one part (monolithic design and functional integration). The additive manufacturing technology comes along with a great lightweight potential, which often results in a reduction of used material. As well, a waste reduction in comparison to the milling process is possible. In addition, the last often discussed potential is complexity for free. [HHD06], [Gebh12], [ReKo16]
These are great potentials in the area of the digitalization, where Additive Manufacturing plays an important role, but they are often not used nowadays out of many different reasons. One of the reasons are the high purchase price of the machines. In comparison to a milling machine, the costs are not much higher, but the risks, which are based on the not fully developed technology of AM, often ends in hesitation [LJMK12]. Another pain point is the high effort which is needed for the integration of a new production technology into the work of an engineer. Today´s engineers often

work under high time pressure. When they have to design a part, the known development and production processes often seem the faster ones, so there is no way to their heads for AM. One of the often said sentences if someone speaks about the decision for or against the additive manufacturing technology is: "this is how we always do it, this way it goes faster". This sentence brings up the next issue, the problem is not the knowledge about the technology it is more the psychological barriers in the heads of every employee who is scared about the industrial digitalization. Most employees, especially in small and medium-sized enterprises are scared about what a new technology brings to their companies. The engineers are afraid about the time aspects and the workers are afraid of automatization and possibilities of replacement. [InAl]

However, the digitalization is on its way and the time for a change in thinking is there. The additive manufacturing technology is a big driver in the digitalization and in the field of industry 4.0 [Künz16]. In the German industry, 40% of the companies are just at the beginning of the digitalization [www1]. Here is the point for changing and convincing arguments. This starts not only at the unit of the engineers, rather is it necessary to integrate every unit of a company, also marketing and sales management, into the digitalization development [Pelz10].

The easiest way to start the increasing of acceptance is in the construction area. As said before the design tasks of today´s engineers are faster to handle when they use known production processes. Especially under the consideration that the work is characterized by adaption and variation constructions. Thus, an easy and fast way to find the most promising parts for the production with additive manufacturing is needed, so the engineers are able to concentrate on the design tasks. The aim is to reduce the level of frustration by avoiding of setbacks because of not additively manufacturable parts. [Schu12] [VDMA16]

Through this facts it becomes more and more obvious, that a selection process is needed, which shows engineers the exciting parts out of the product portfolio. One of these selection process tools was developed by the Paderborn University, called "Trade off Methodology", which is presented in the following chapters. Additionally, possibilities for the further development are shown.

Trade-off Methodology – State of the Art

The development of the Trade-off Methodology (TOM) started 2015 in the ESA Project "NewStructure". The aim of the Methodology is to filter several parts, out of a company's existing product portfolio, which might have potential to be manufactured with the additive manufacturing technology. For a good efficiency, the first step in the matrix is to check different K.O. criteria, like part size vs. machine size and printable material. For those parts that are still feasible to be manufactured with AM, a detailed investigation through the TOM criteria has to be done (see Figure 1).

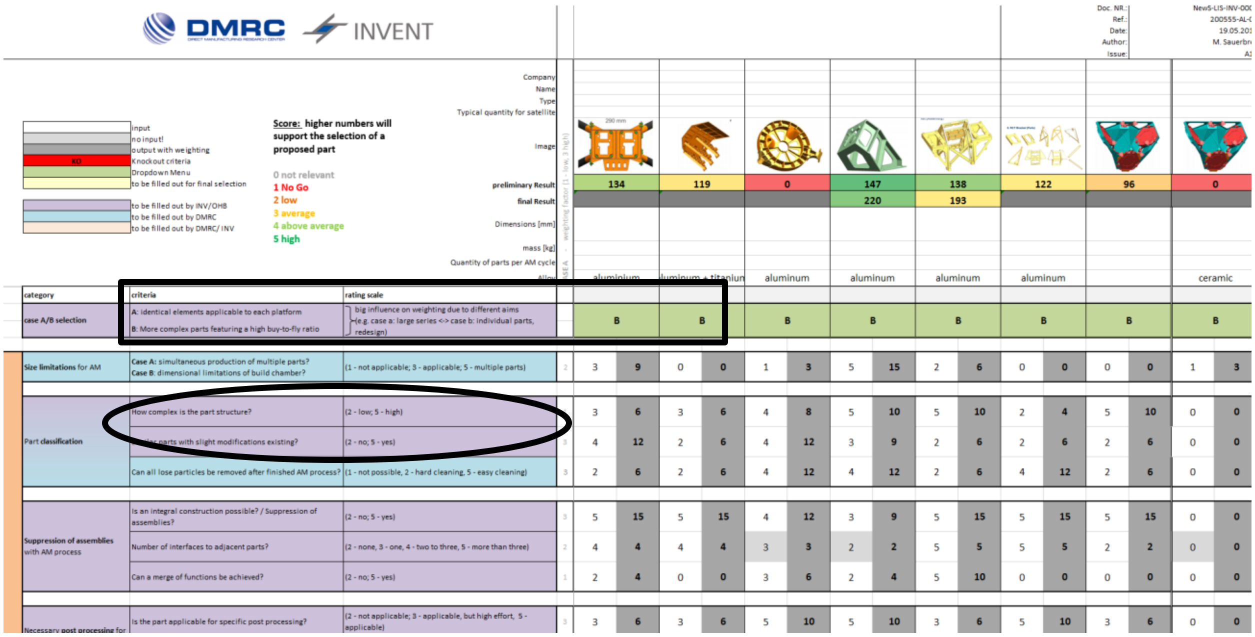


Figure 1: TOM Excel sheet; first tab

For every part, the AM specific questions of the matrix needed to be answered. The answers are deposited with a scoring system from one to five points. The target definition of an AM redesigned part are varied in the point of lightweight potential, the integration of functions or the other earlier named potentials. Hence, for a better assessment, two categories were implemented, in which the parts have to be divided. The first category is for the parts that should be printed in the way they are, engineered with small adaptions for the additive manufacturing technology. The second category involves the parts which should get an overall product optimization for the production with AM (see Figure 2) [LJRK14].

criteria	rating scale			
A: identical elements applicable to each platform B: More complex parts featuring a high buy-to-fly ratio	big influence on weighting due to different aims (e.g. case a: large series <-> case b: individual parts, redesign)		B	A

Figure 2: Enlarged view on the part categories

During the first development phase, the main focus was more on finding the right questions regarding manufacturability, than on a user-friendly handling of the matrix. As shown in Figure 3, the options for answers in the first tab are just given in a much reduced way. The user just get the information, that there is a 2 to 5 rating system.

How complex is the part structure?	(2 - low; 5 - high)	1	4	8
Similar parts with slight modifications existing?	(2 - no; 5 - yes)	3	3	9

Figure 3: Enlarged view on the answer and weighting system

The exact classification of the deposited scoring system has to be looked up on the second tab of the Excel table (see Figure 4Figure 4). Here the user finds a description to every value, in which the part can be ranged in. At the initially usage, this second tab is important for the user's understanding of the methodology, because the value explanations in the first tab are very short and often only given for the maximum and the minimum value.

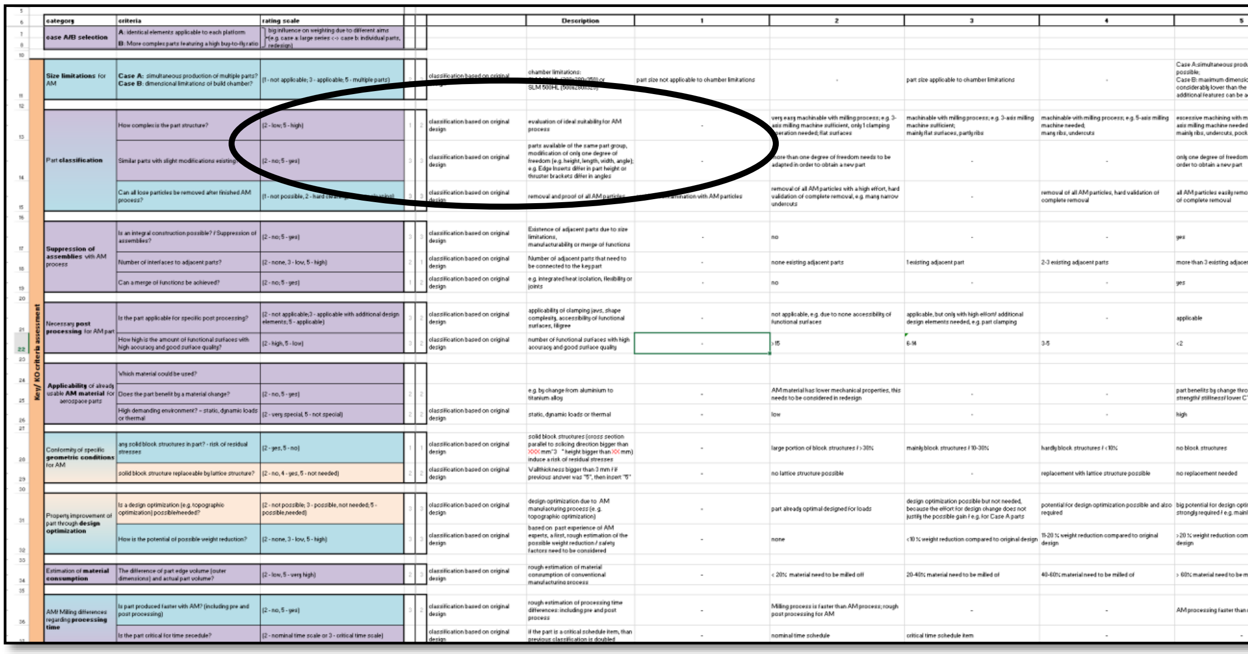
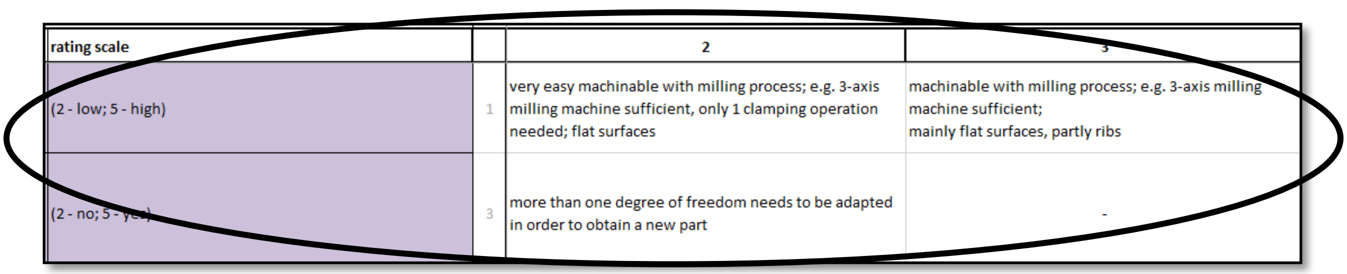


Figure 4: TOM Excel sheet, second tab

Thus the problem with this matrix is, that the structure of two excel tabs makes it not user-friendly and unclear in the operation. Furthermore the description of the values in the second tab leaves the user a great scope for interpretation (see Figure 5). It is defined that the part gets two or three points when the conventional manufacturing is done on a 3-axis milling machine and four or five points for a 5-axis milling machine. But the interpretation about the surface, ribs and under cuts will be done by the employee, who works with the matrix. Thus, the part ranking is very subjective despite a detailed description for every single value.



rating scale		2	3
(2 - low; 5 - high)	1	very easy machinable with milling process; e.g. 3-axis milling machine sufficient, only 1 clamping operation needed; flat surfaces	machinable with milling process; e.g. 3-axis milling machine sufficient; mainly flat surfaces, partly ribs
(2 - no; 5 - yes)	3	more than one degree of freedom needs to be adapted in order to obtain a new part	-

Figure 5: Enlarged view on the rating scale in the second tab

Based on the focus of the NewStructure project, the questions for the analysis of feasible AM parts were defined very specifically for the aerospace industry. Especially the criteria on weight reduction were highly rated in the scoring, due to the high financial impact in the aerospace industry.

Trade-off Methodology –First Improvement Activities

The first improvement activities attempted to create a cross-industry methodology with a user-friendly design. All criteria have been revised in their terminology to get a phrasing that is cross-industry understandable. For a more detailed scoring system, the two existing categories were divided into four. Thus, the weighting of the questions could be more focused on different aims of redesign and parts:

- **Criteria A: Change of the manufacturing technology**
  The aim for this category is to filter parts, which needs just small modifications to be feasible for the additive manufacturing technology. The actual part design shall be maintained.

- **Criteria B: Lightweight potential**
  For this category the aim is to find parts with a high percentage of solid block structures. For Example milling parts who get their design based on the semi-finished product. This parts could gain a high weight reduction through additive manufacturing.

- **Criteria C: Functional integration**
  Parts for this category needs potential in the improvement of their functionality. Furthermore a reduction of assembly steps is aimed.

- **Criteria D: Overall product optimization for additive manufacturing**
  This category is for parts which have the potential for an extensive redesign and functional optimization.

To get a better usability, to avoid the switch between the different excel tabs and to get a better overview on which answer was chosen, a drop-down system was integrated (shown in Figure 6). So the questions and all answer possibilities are found in the same tab of the excel sheet, that makes the completion of the methodology easier and faster than before.

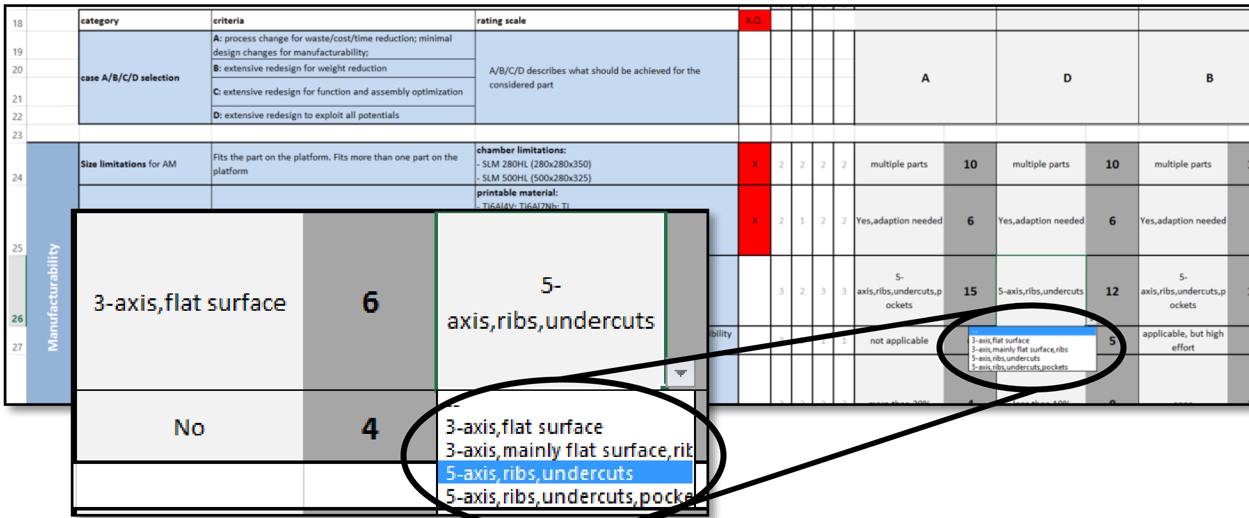


Figure 6: Overworked Trade-off Methodology with drop-down system

During use of the matrix some other weaknesses were discovered, like the missing consideration of plastics parts, which were not important for the NewStructure project but could have a tremendous impact at other industries. Furthermore, it was pointed out, that it is not possible for an engineer to complete the matrix on his own. To get the best results of the methodology, the part analyses has to be done by minimum two people, one who have all important information about the part (responsible engineer of the company) and the TOM and AM expert. Therefore, the results would be still subjective, based on the personal experience. The development opportunities for reducing the weaknesses on a minimum were presented in the next chapter.

Trade-off Methodology – Development Opportunities

The Trade-off methodology should be further developed in the project OptiAMix, with the aims of prevention of subjectivity and elimination of all previously discovered weaknesses.
The first step to develop a less subjective matrix was the creation of a questionnaire, which concentrates on the individualized company strategy and focuses on the aims of each possible AM part. After a couple of iteration loops with the industrial partners about the content of the questionnaire, the outcome are two worksheets. In the first one, the company strategy should be explained. To get some general information about the company the industry affiliation is requested and if the company operates as an OEM or as a supplier. Out of this information the used norms and standards in the industry can be filtered, which have a great influence on the scoring system for the potential AM parts. Another important point for the scoring in the matrix is the strategic orientation. The companies can choose between technology, market, costs or price leadership (multiple answers are possible).

- **Technology Leadership**
  Companies with superior development tools or the most demanding production techniques. In contrast to the innovation leadership a technologically outstanding production is needed, innovative products are not necessary

- **Market Leadership**
  Companies with the largest market share

- **Costs Leadership**
  Companies with the lowest production costs in the competitive environment. In many cases, cost leadership is a prerequisite for price leadership

- **Price Leadership**
  Companies with the aim to offer always the best price in the defined market. A price leadership can usually only be reached and held over a short time period. It often conduced to expand the own market share or keep away from competition

[www2]

So the overarching aims for the company's product portfolio can be specified. At the end there are some questions about the management strategies for spare parts and tools, to get a complete company overview.

The second questionnaire is for the aim of the product itself. The general information of the part to be examined are the assembly group, the quantity per year or the batch size. These are the crucial information for the additive manufacturing feasibility analysis. For a complete product-related weighting of the TOM the aims of the product in the sectors costs, time, weight reduction, function integration and increase of operating features are important. Furthermore, the construction type possibilities like integral, differential or hybrid construction are asked.

With these two questionnaires and the current methodology, the part analysis is a manual workflow (see Figure 7), which still needs two experts. The first one is an employee from the company, who have the knowledge of all necessary information about the considered part and the company strategy. He has to complete the questionnaires. The second one is the TOM expert, who adapts the weighting of the methodology based on the results of the questionnaires. After that, both experts fill in the TOM, under the consideration of different influence factors between some questions. On this way, a promising part can be selected for the additive manufacturing process.

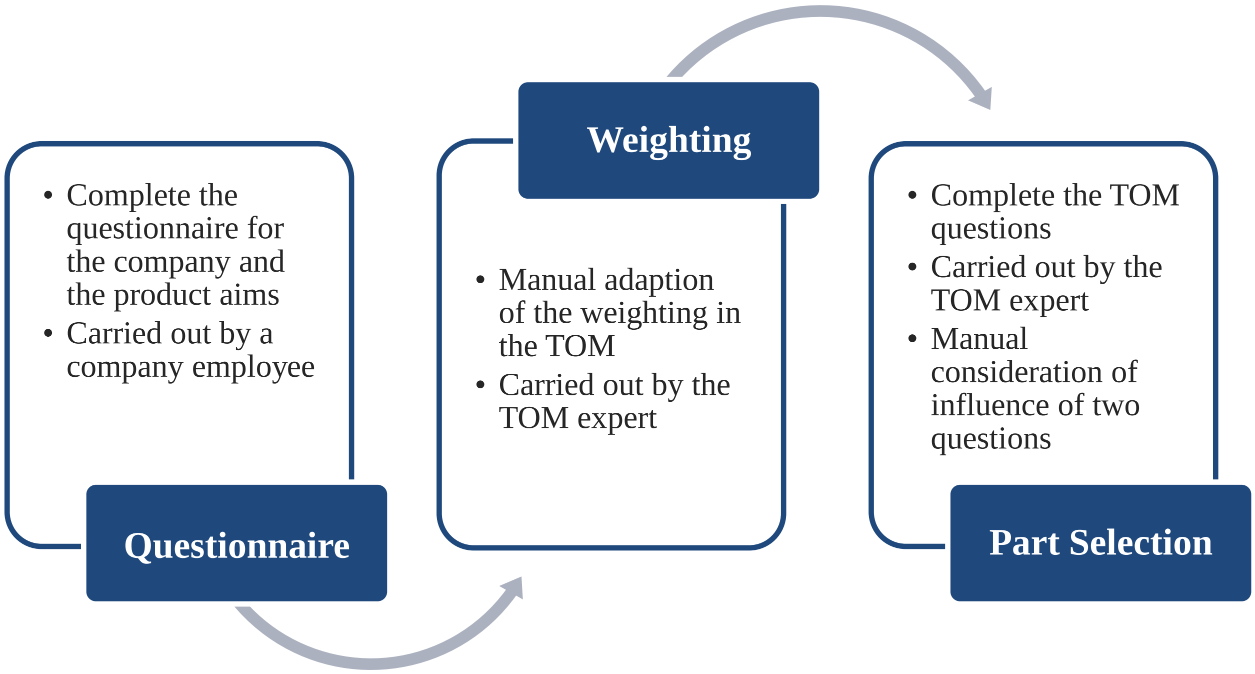


Figure 7: current workflow

Out of the current workflow can be derived that there is still a lot of optimization potential for the Trade-off Methodology, especially in the weighting area. The weighting should be automated and the missing aspects integrated. The matrix needs to deal with plastic parts as well as casting parts and the number of needed molds. The number of parts and the effort for an assembly needs to be requested. The influence between the criteria has to be analyzed and an interactivity between these questions has to be integrated. An Example is the question about solid block structures. A part with a high percentage of solid block structures is normally not feasible to be manufactured with AM and get a low rating. However, when the block structure can be replaced by lattice structure, it would have a positive impact for the production with additive manufacturing and the question needs a high rating. Another improvement for the matrix is the cost analysis. A detailed comparison between the conventional and the additive manufacturing process is the aim. The comparison started with the material and machine hourly rate costs and ended by how high is the work load for one employee for the monitoring of a milling and an AM machine.

The OptiAMix project would like to exhaust the weaknesses of the matrix over the project duration in the next two years.

Outlook and Summary

In the OptiAMix project, it is foreseen to develop a tool that fulfills all requirements for a multi-target-optimized part. To integrate the TOM into this tool it is necessary to get a less manual workflow for the matrix. The idea is to merge the questionnaires with the Trade-off methodology, so the weighting of the TOM questions will be done automatically (see Figure 8). The most important challenge for this task is to formulate all questions in such a way, that they are understandable across all industry sectors. The formulation of the current questionnaires are a good start, but only based on the company branches, which are involved in the project. Furthermore, it is necessary to establish a complete influence and weighting matrix, which covers all dependencies between the answers of the questionnaires and the questions in the TOM.

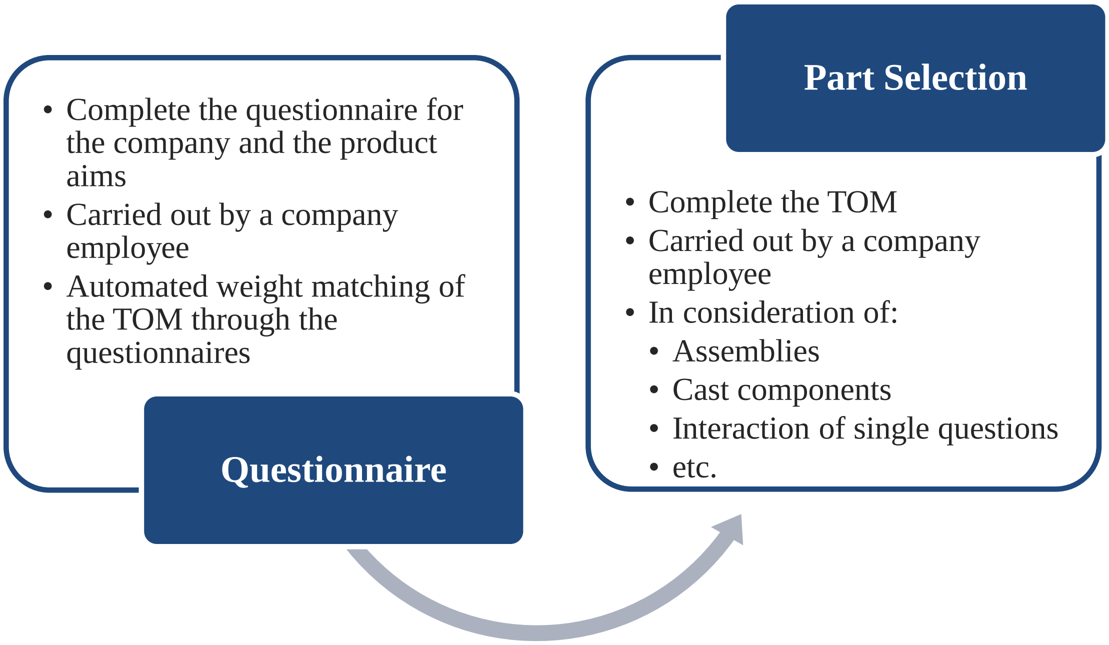


Figure 8: future workflow

Beside the optimization of the workflow, the questions of the TOM will be also revised. Like said before, there are some weaknesses that have to be looked at during the project. The first important point is that the TOM needs the integration of thermoplastic parts. The current focus of the methodology is on metal milling parts. That comes up with the next point, assemblies need to be analyzed. How many parts need to be manufactured and how high is the installation effort, are two questions which have a great influence on the AM capability for a part. At the end, the costs have to be integrated. Therefore, the manufacturing costs, like material and machines costs, will be analyzed. In addition, there will be a comparison of the personnel placement, especially between milling, casting and additive manufacturing.
If all this steps will be done in the project, the TOM will be a fast and user-friendly tool to filter an existing product out of a company's product portfolio, which can be done by only one company employee.

Acknowledgement

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