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Supporting the Decision Process for applying Additive Manufacturing in the MRO Aerospace Business by MADM

Gereon Deppe*, Rainer Koch*

*Direct Manufacturing Research Center (DMRC) and Chair of Computer Application and
Integration in Design and Planning (C.I.K.), The University of Paderborn, Pohlweg 47-49,
33098 Paderborn, Germany

Abstract

The spare part industry in aerospace is highly demanding. For conventional manufacturing technologies it is difficult to meet these requirements. In contrast to that, the design freedom of Additive Manufacturing enables the production of complex and lightweight parts. The lack of experience with this technology hampers the decision where Additive Manufacturing can be economically applied. The cost drivers have to be newly evaluated and holistically investigated. Supply chain advantages have to be considered during the decision process, too. Therefore, aerospace characteristics are analyzed within the paper and a methodology based on Multi Attribute Decision Making (MADM) is introduced. To do so, the cost appraisal for Additive Manufacturing has to be detailed. Additionally, changes in the supply chain have to be identified and quantified. Quality criteria have to be taken into account as well. In the end it is shown how these influence factors can be combined to create a decision support.

Introduction

The aerospace industry is characterized by a high economic pressure through the fierce global competition and high value assets. It is further driven by a constant growth of the industry but decreasing earnings [Boei15]. Therefore, the airlines have to maximize the availability of their fleet in order to increase the aircraft's operation time [PwC11] [Lanz11]. In order to achieve this a regular maintenance is mandatory. This is one of the reasons why expenses for maintenance are one of the major cost drivers in aerospace besides costs for fuel [Mens13a]. For achieving a cost reduction for both aspects the prime manufacturers need to apply new technologies to get to more efficient part designs which offer enhanced reliability and durability but also a lower part design. Both aspects can be improved by Additive Manufacturing (AM) [DRK15]. The flexibility of this technology enables a lightweight design for aerospace parts and - due to the layer based production and the concurrent complexity-for-free - an economic manufacturing [Gebh13]. Furthermore, it is possible to get to more efficient part designs which leads to enhanced reliability and durability. Hence, maintenance costs decrease as parts can be optimized for their function rather for their producibility. Consequently, parts will fail less and a lower part weight will reduce the fuel consumption and decrease the operating costs [DRK15] [Grun15].

In all, the potential for AM in aerospace is high and can help the industry to decrease not only the operation costs but also to become more environmentally friendly [GEKW12]. Still, the technology is not integrated in current processes [DeKo14]. Companies often lack experience with this new technology. This is why a methodology and tool is required that supports the decision whether it is economically reasonable to apply the technology for a certain repair or production case or it can help to compare the benefits of an optimized design to the conventional one. This is especially important as AM should not be limited to the production costs but requires a broader approach to assess all benefits, for example a shorter supply chain through a production close to the point of use and a life cycle analysis [DeKo15] [LJMK13]. Therefore, a decision support is required that helps companies to choose the most cost-efficient technology for a certain use case.

Decision Alternatives

In order to develop a decision support, the decisions that can be made have to be known. Therefore, the general, operational procedures of MRO provider have to be taken as a basis. If a defect part is inspected at the workshop and classified as not repairable, a new one has to be ordered from the OEM. If a repair is possible it has to be assessed which resources in terms of material, tools and personnel are required. If an economic repair solution can be found, a work order is started. If not, it is checked whether the part can be stored to repair it at a later point of time or whether the repair can be outsourced [Mens13b]. The decision support in this paper focuses on the selection between three alternatives:

- in-house repair applying AM
- production of a conventional milling part
- the acquisition of a new part

The Decision Component is positioned in the operative field of a MRO company. It focuses on the examination of the defect part and the decision which path to choose. Therefore, the aim is to develop a concept to calculate a cost-efficient repair. The concept supports the decision process as a standardized instrument to assess the costs of the decision alternatives and to save time and costs during this process.

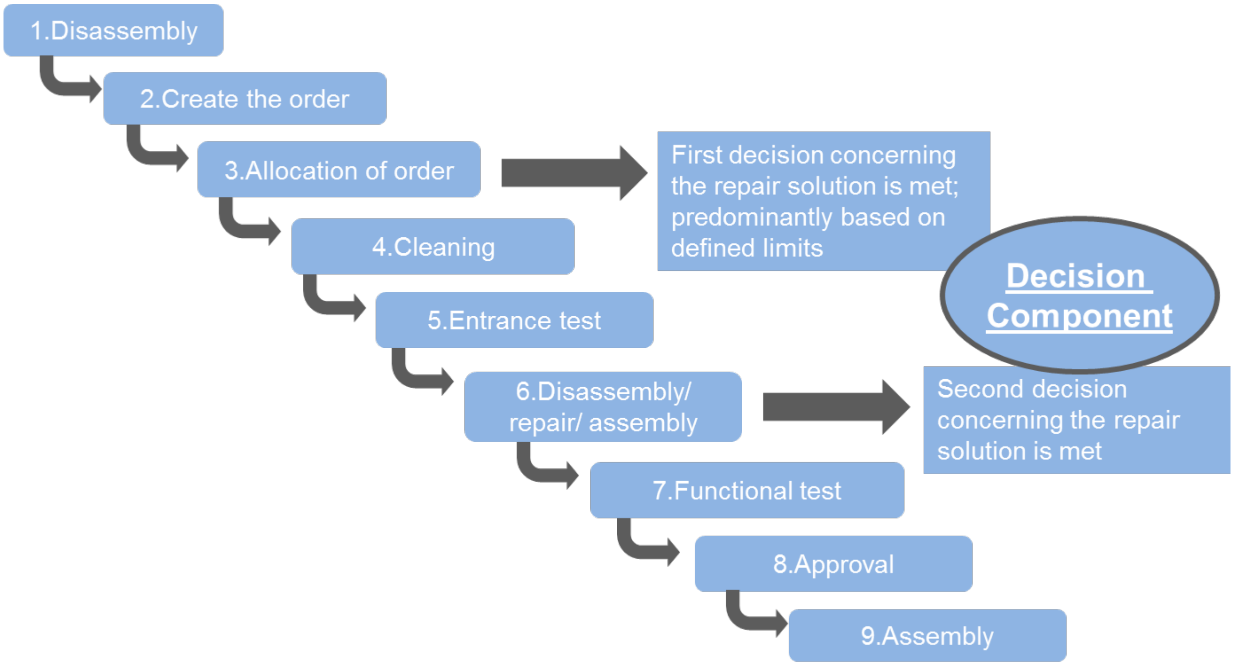


Figure 1: Decisions to take during the MRO procedure [Mens11]

Figure 1 combines the previously described decisions to take with the usual repair procedure. If a defect component is identified in an aircraft it gets dismounted from the aircraft and a work order is created. It is then sent to the MRO workshop for further assessment of the defect. There, the first inspection determines whether a repair is at all possible with the available technologies or whether it has to be scrapped and newly purchased from the OEM. If this is passed then the component gets cleaned and tested in detail. When the actual defect part has been detected the final decision has to be made which technology should be applied. This process is supported by the Decision Component which determines the cost-efficient repair solution. Its operational decisions are illustrated in Figure 2. The repair is then started and afterwards the component is assembled again. A functional test assesses that the component is fully functional so that the approval can be issued. Afterwards, the component is ready to be installed in an aircraft again. [Mens11]

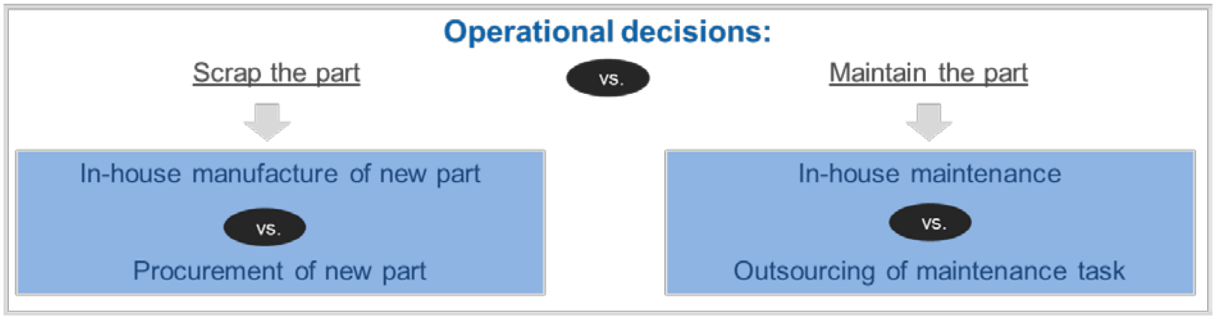


Figure 2: Operational decisions for a defect part

Key Assumptions for the Use Case of the Decision Component

In aerospace, Additive Manufacturing is currently not a standard technology. In order to reproduce a use case for the Decision Component some assumptions have to be made. First of all, it is assumed that for this technology qualified processes exist. They are implemented in the Component Maintenance Manual (CMM) or at least can be included by EASA Part 21/J Design Organizations without major difficulties [EASA21A-J-001][Hins12]. It is further assumed that the required quality for a certain part or repair process can be achieved with AM. Otherwise it would not make sense to choose the technology for a comparison with conventional technologies as quality is a key factor in aerospace.

It has to be stated that the Decision Component does not contain a direct functionality to assess the break-even point of a part redesign. Nevertheless, the Decision Component is able to compare and quantify ecological potential that arises through an optimized design during the product life cycle.

Decision Support Fundamentals

Companies are facing an intense competition in their market driven by the globalization; and the scarcity of resources pushes them to an adaption of their processes [AbRe11] [WBM11]. A transformation is required that leads to the integration of new technologies and processes in order to gain a competitive advantage and to offer innovative solutions to their customers. Therefore, decisions have to be taken which are influenced by various factors from the market and the company’s environment. To be able to consider multiple factors at the same time in such decisions, tools have to be available that support this process. Especially in aerospace, where the life cycle is particularly long (up to 65 years, 25 years of operation time for every aircraft and 20 to 40 years of sale time), decisions have a far-reaching impact with high economic and technological risks [SGF+08]. A thorough and rational decision making process is mandatory. The immense time and cost pressure requires airlines to maximize the availability of their fleet to compete with their competitors. Therefore, a holistic approach is necessary that reveals possible savings and includes procurement, production and logistics. An economic efficient production technology with high productivity, time, cost and quality orientation has to be chosen. Additive Manufacturing has already been identified as a promising influence factor for the aerospace industry with its focus on short-lead times, resource efficiency and lightweight design opportunities. It enables the improvement of companies’ specific added value.

Terminology

Almost every action leads to a decision problem that can be solved quite simple for trivial problems but can also become very complex with many influence factors and requires supporting tools for getting to a rational solution. At an entrepreneurial level, either strategic or operational, the decision making is an extensive research field. This is driven by the fact that wrong decisions can have fatal impacts on the business success. The decision maker is interested in an optimal action alternative with the support of a decision support to handle the complex situation. If there is no optimal solution the tool should determine the most efficient alternative with regard to the given requirements and restrictions. Problems can arise through uncertainty, missing information or excessive effort.

The underlying decision theory is divided into descriptive and prescriptive theories. The first one deals with the question how decisions are made while the prescriptive theory focuses on the process of finding a solution in order to achieve a high degree of fulfillment [Laux07]. For solving decision problems it is usually necessary to identify the influencing parameters and to include them in the model. They are split into the areas “decision rule” and “decision field”. The decision field can be further characterized by the action alternatives, which reflect the number of possible choices, by the boundary conditions, which describe the environment, and by the consequences, that define the effects of the occurring impacts of the decision variables. For the decision rule, which determines the target system, two further topics can be consulted: the optimization criterion as a leading command variable to evaluate the criteria and the preferences which allow for the weighting as a transparent evaluation scheme of subjective assessment. [EWL10]

Most target systems pursue more than one objective so that the decision making is located in the field of the Multi Attribute Decision Making (MADM). The structuring of relevant factors is required to map the rising complexity caused by the multitude of aims. This allows for a processing by IT systems. The MADM process driven procedure exhibits different phases. It starts with the problem identification and is followed by the subsequent problem structuring as the basis for the development phase which leads to the modeling as the third step. Thereupon, the decision making can begin which generates a proposal for solution and overall finishes the selection phase. [BeSt02]

In the course of classifying the present multi attribute decision problem the following assignment can be found on the basis of the prescriptive approach: The problem structure is characterized by a semi structured specification, the decision is made under certainty due to its operative character and the target system is, as described earlier, multiple. A discrete solution space with a finite number of action alternatives is therefore necessary to solve the problem. When transferring the described aspects to the existing use case, the following model in Figure 3 can be composed.

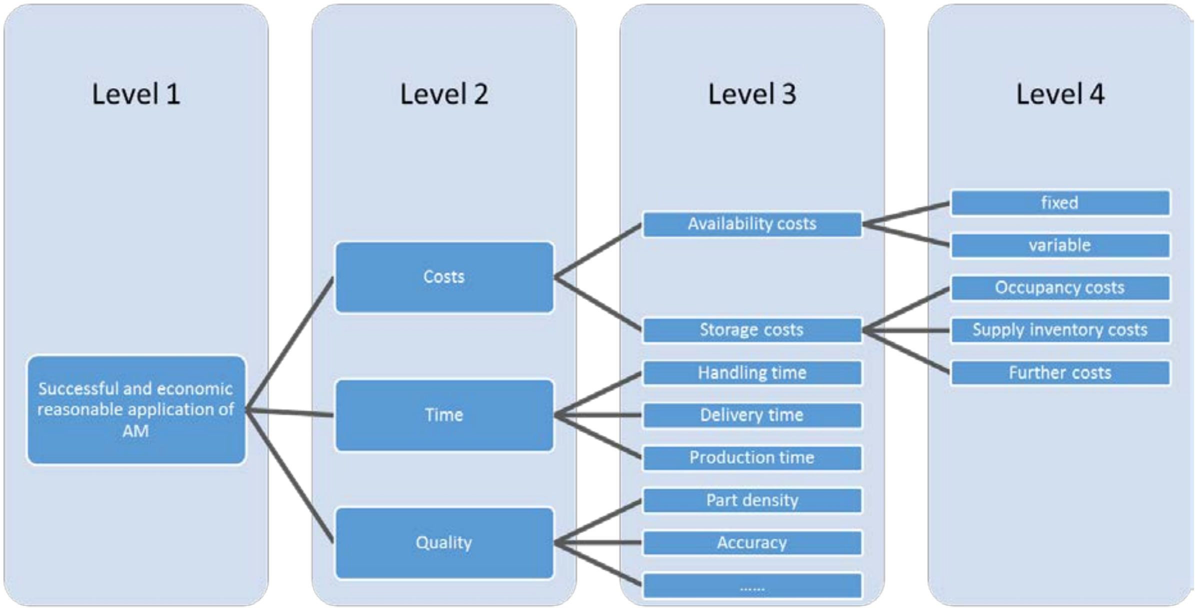


Figure 3: Approach for the decision model on the basis of the relevant criteria

Multi Attribute Decision Analysis

There are many different MADM approaches that are characterized by different procedures. The cost-utility analysis for example uses a pairwise comparison by an explicit scale to determine the advantageous choice. Outranking models also use pairwise comparisons but they use strict and weak preference values for that. This is beneficial for the existing problem in the MRO industry as the decision support has to compare logistics and production optimizations which exhibit very different characteristics and impacts which makes it difficult to compare each. There is an infinite number of indifference shapes that has to be expected for the criteria evaluation in this process and requires a highly flexible manageability of the methodology. Nevertheless, the complexity should be on a low level in order to decrease the training effort for new users and increase the usability [GRS10]. The methodology PROMETHEE defines preference functions which are able to value differences between the single alternatives. To do so, threshold values have to be defined. While there does not exist an objective catalogue for the selection of the thresholds PROMETHEE only uses these thresholds to distinguish preferences from indifference regions of general assessment criteria. Thus, their impact on the decision-making is much lower than for example for ELECTRE and generates more robust results [Hart06]. It has to be stated that the choice of a decision tool highly depends on the relevant problem and its characteristics and has to be evaluated again for every new problem.

The preference functions describe separate part worth utility functions for each pairwise comparison. They indicate the preferences of the decision-maker even for insufficient information because they map the predominant difference of a certain criteria weighting [Geld14] [Goet08]. The preference degree is a value between zero and one and determines the how much an alternative is preferred [IsNe13]. If the value is one then this is a total preference. Zero connotes none preference. A value between those boundary values indicates a small preference. For cost items linear preference functions can be chosen. Only an indifference threshold has to be given so that differences higher than the threshold describe a strict preference between the alternatives otherwise it is only a lower one. For time aspects a step criterion can be chosen. This requires both, an indifference value as well as a preference threshold. Differences below the indifference value connote an indifference and for values

above the preference threshold a strict preference is existent. Values between those two thresholds indicate only low preference [Geld14]. The quality parameter are often very heterogeneous and do not show a uniform dimension. Usually, quality parameters can be quantified such as the surface roughness for example. The process stability can be realized with the help of an exponential function whereas the inflection point states at which point the preference increase resp. decreases.
For the present use case a selection of the preference functions is shown in Table 1.

Table 1: Parameterization of some decision criteria

Criterion	*Min/Max*	*Preference-function*	*q-value, σ-value*	*p-value*	*Unit*
Direct provision costs	Min	Type 3	n/a	500	$
Indirect provision costs	Min	Type 3	n/a	450	$
Occupancy costs	Min	Type 3	n/a	100	$
Storage costs	Min	Type 3	n/a	100	$
Other costs	Min	Type 3	n/a	100	$
Handling time	Min	Type 4	1	2	h
Shipping-, delivery time	Min	Type 5	2	6	h
Build time	Min	Type 5	1	3	h
Part density	Max	Type 3	n/a	3	%
Accuracy (dimensional)	Max	Type 3	n/a	2	mm
Surface condition	Min	Type 3	n/a	2	5-point
Process stability	Max	Type 5	0	5	%

For the different alternatives the input and output flows are then determined. The output flow Φrepresents the strength of an alternative with values between 0 and 1. The higher the value, the better it is. The input flow Φconstitutes the weakness of an alternative where the values are between 0 and -1. The closer they are to -1 the weaker is the alternative. The sum of both flows sums up to the net flow Φ If this net flow is higher than a compared alternative this usually is the preferred one.

Conceptual Design

In order to be able to use the decision support not only theoretically but also for real-world case studies the Decision Component is implemented as an Excel Tool in order to guarantee the ability to run on almost every standard equipped office computer. Excel is a spreadsheet analysis that is able to handle complex operations. Integrated formulas uses the user input to calculate a result. In addition to that, the software can visualize the generated data. To further extend Excel's opportunities individual applications can be developed by utilizing the programming language Visual Basic for Application (VBA).
Clicking on a communication interface (e. g. button) activates the defined programming code that contains instructions what activities have to be conducted and the result is then given. There are different communication interfaces which can be used to provide input or to start a sequence. Every interface exhibits different features that are required for certain conditions. They can be linked or interrelated to others. Their action has to be defined in the programming

code and leads to a reaction of the tool to user input. Through the combination of interfaces, algorithms and sequences complex procedures can be built.

The Decision Component is extended by VBA in order to enhance the functionality and the graphical interface. At the basis of the tool there is a calculation methodology for AM that has been developed at Paderborn University resp. the Direct Manufacturing Research Center (DMRC). In order to gather the required information for the calculation the tool is divided into different subsystems (see Figure 4).

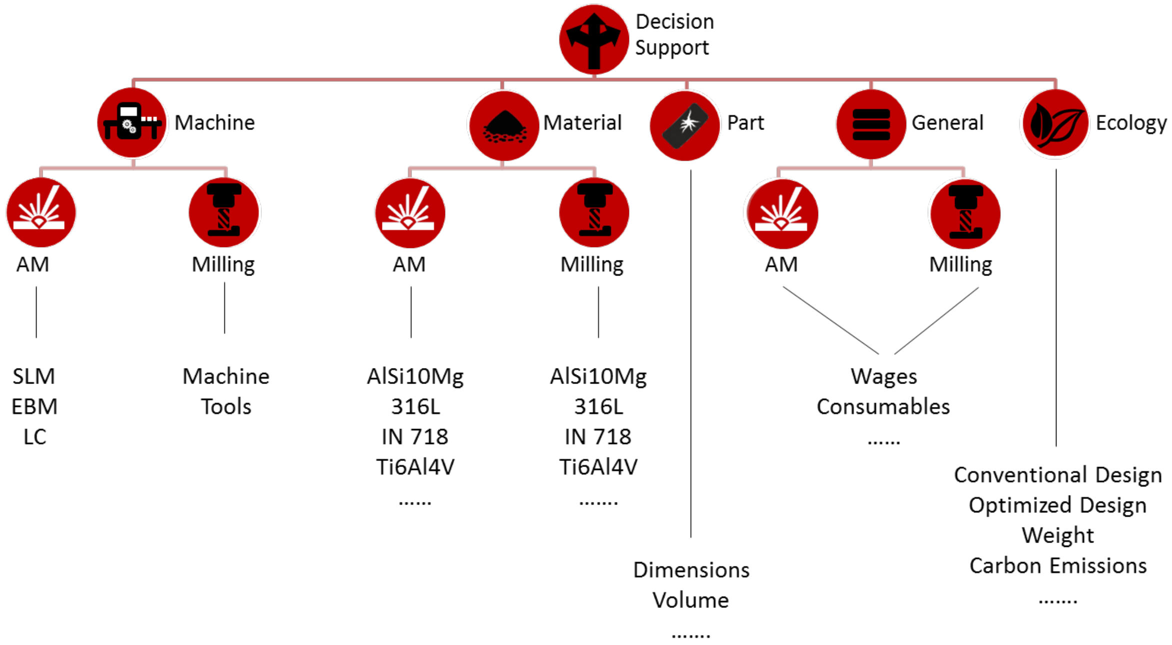
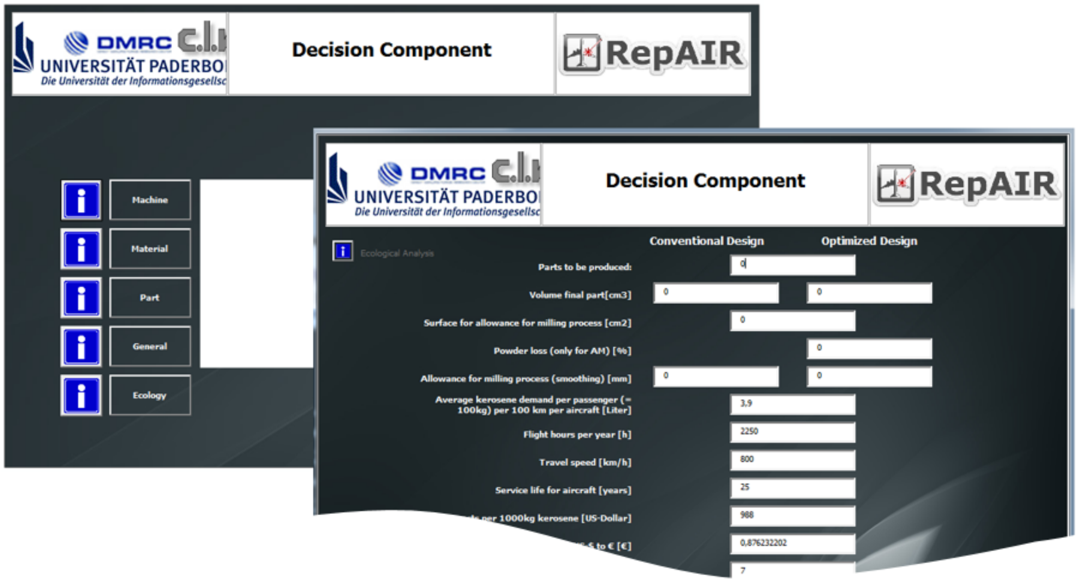


Figure 4: Overview of the configuration units for the Decision Component

They have to be filled in to provide the data basis for the calculation and decision making. This process can be supported by pre-defined master data that can be overruled manually but enables an easier and faster operation of the tool. The system has to consolidate the given inputs and to ensure that all calculation relevant data is available. In comparison to an earlier version of the tool which is described in [DLK15] it has been extended by an additional ecological analysis that is able to compare a conventional part design with an optimized one.



	Conventional Design	Optimized Design
Parts to be produced:	0	
Volume final part[cm3]	0	0
Surface for allowance for milling process [cm2]	0	
Powder loss (only for AM) [%]		0
Allowance for milling process (smoothing) [mm]	0	0
Average kerosene demand per passenger (= 100kg) per 100 km per aircraft [Liter]	3,9	
Flight hours per year [h]	2250	
Travel speed [km/h]	800	
Service life for aircraft [years]	25	
per 1000kg kerosene [US-Dollar]	988	
$ to € [€]	0,876232202	
	7	

Figure 5: Start page of the tool and ecological subcomponent

As every company interacts with the environment it is important to be sustainable in consuming natural resources. The ecological awareness is rising and the aerospace industry is seen as a major polluter which is why this topic is particularly sensitive for this industry [Mens13a] [LHNB14]. To meet this demand for the ecological analysis of the business processes the Decision Component has another subsystem dedicated for the ecological assessment. Different features can be assessed. First of all the subsystem is meant to compare different designs of a part so that the layout is divided into conventional and optimized design. The positive economical impact of topology optimized part designs has already been presented in various papers and is a major driver of the AM technology in aerospace [DRK15] [ReKo15]. Values for the conventional design can be filled in as well as for an optimized design which is most likely a lightweight construction. This is followed by several inputs for assessing the service life of the part and the fuel consumption that it causes during this time due to its weight. Directly related to the fuel consumption are the carbon emissions which are calculated simultaneously [LHNB14]. In order to map changes in the supply chain and calculate the arising costs and carbon emissions the part's travel distances during production for truck, train, ship and aircraft can be stated. For the long service life of aircrafts and its components it becomes necessary to include price growth rates for kerosene and emission permits which can be specified at the end. For a faster handling there are also pre-filled in master data that can be overruled by a manual input. This data is focused on the aircraft life and emissions as this information is not at hand for everyone.

When all configuration units have been filled in the calculation can be started. The costs for AM, for milling and the procurement of a new part are calculated as well as the time aspect examined. The results are shown with different charts. The main cost drivers and their shares are shown as well as a quality, cost and time analysis. Based on the previously described methodology the preferred and cost- or time-efficient solution is determined. In order to meet the documentation needs of aerospace the tool creates several documents with all user input and calculation/result outputs and stores it in a defined directory. This increases the traceability for decisions that have been made and can be used to further improve algorithms etc.

Summary and Outlook

Due to the specific characteristics of aerospace, Additive Manufacturing is suited to be applied in the MRO aerospace industry. The required flexibility for low quantity and highly complex products cannot be realized by conventional technologies without reverting to extensive warehousing. The usefulness of applying AM for a certain use case has to be proofed. Therefore, a methodology is required that supports the decision process. Especially, because companies are not experienced in assessing the production costs of AM and its additional benefits have also to be taken into account to fully exploit the benefits which AM offer.

There are many options to use AM in the MRO business creating potential economic, time and ecological benefits. To assess these benefits and to clearly state them a combination with software solutions is mandatory. This always has to be compared to conventional technologies as AM is still limited in its utilizability. As the technology is currently not approved for aerospace, being a Design Organization is crucial for applying the technology as a MRO. This will change when more experience with this technology is gained and more certified parts and processes will be available. The application of AM by OEMs and the prime manufacturers will foster this development as it will then become necessary for MRO provider, too.

A framework to assess economic, time and ecological factors has been developed and integrated in a software tool. Based on identified key cost drivers different configuration units have been set up. They provide a standardized process to gather data that is required for the cost and time calculation of the repair choices. It is supported by predefined data but can always be adjusted manually. The tool calculates the expected costs for AM, conventional technology and the procurement of a new part from the OEM. The evaluation is illustrated by charts showing the share of each cost driver from the overall costs. Additionally, quality, costs and time graphs provide information of the key elements of MRO business showing the overall best solution for the defect part. A further ecological analysis can be conducted in order to compare the environmental impact of an optimized design or supply chain alterations with those of a conventional designed part. This is still based on some assumptions, e.g. that qualified AM processes exists and the required quality can be achieved. The selection of an alternative is conducted by a Multi Attribute Decision Analysis based outranking approach called PROMETHEE which has been chosen due to the specific requirements and characteristics of the application. It is able to use different types of preference functions that can be applied for qualitative and quantitative influence factors. It is able to identify the best alternative even if this is not obvious or if there are strict preferences due to a time critical defect part.

The concept for the decision component allows the monetary assessment of repair processes especially for AM. The documentation of the complete input and output data fosters the transparency and traceability of decisions which is a crucial aspect in aerospace.

Now that this methodology has been set up and included in a tool, for future work a detailed comparison of sample parts/case studies is required in order to assess the validity of the tool. Therefore, it has to be improved in the evaluation of the quality and time aspect to allow a detailed analysis with real use cases and to fully exploit the tool’s functionality. For future work the tool can be enhanced by strategic levels and additional functionality such as calculating the product life cycle costs. The aerospace specific tool can also be adapted to the needs and specifics of other industries in order to proof its general applicability.

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Literature

[AbRe11] Abele, Eberhardt; Reinhart, Gunther (2011): „Zukunft der Produktion: Herausforderungen, Forschungsfelder, Chancen (English: Future Production: Challenges, research areas, chances)“; München: Carl Hanser Verlag.

[BeSt02] Belton, Valerie; Stewart, Theodor J. (2002): „Multiple Criteria Decision Analysis – An Integrated Approach“; Massachusetts: Kluwer Academic Publishers.

[Boei15] Boeing (2015): Current Market Outlook 2016-2035. Hg. v. Market Analysis. Boeing. Seattle, WA. URL: http://www.boeing.com/resources/boeingdotcom/commercial/about-our-market/assets/downloads/cmo_print_2016_final.pdf

[DeKo14] Gereon Deppe, Rainer Koch (2014). Exploring the influence of an Additive Manufacturing integration on future MRO processes in aeronautics. RTejournal - Forum für Rapid Technologie, Vol. 2014. (urn:nbn:de:0009-2-39586)

[DeKo15] "Exploring the supply chain opportunities of Additive Manufacturing in aviation’s spare part industry", 5th Programme trade forum “Aviation“, RapidTech, Erfurt, 10.-11.06.2015 (ISBN: 978-3-932875-40-3)

[DLK15] Gereon Deppe, Christian Lindemann, Rainer Koch: "Development of an economic decision support for the application of Additive Manufacturing in aerospace", 26th Annual International Solid Freeform Fabrication Symposium, Austin, 10-12.08.2015

[DRK15] Gereon Deppe, Thomas Reiher, Rainer Koch: "Exploring the cost and lifetime benefits of a topology optimized aerospace part applying additive manufacturing", Production Engineering and Management, 5th International Conference, October 1 and 2 in Trieste, Italy. (978-3-941645-11-0)

[EASA21A-J-001] European Aviation Safety Agency: “CM – 21A – J – 001 - Notification of a proposal to issue a certification memorandum”, Issue 01, 9.7.2012, online available at http://www.easa.europa.eu/certification/docs/certification-memorandum/EASA%20Proposed%20CM-21A-J-001%20Issue%2001_SBs%20related%20to%20ADs_PUBL.pdf, last checked on 23.10.2013.

[EWL10] Eisenführ, Franz; Weber, Martin; Langer, Thomas: „Rationales Entscheiden (English: Rational decision-making)“; Heidelberg: Springer, 2010, 5. Auflage

[Gebh13] Gebhardt, Andreas (2013): Generative Fertigungsverfahren: Additive Manufacturing und 3D Drucken für Prototyping - Tooling – Produktion. Carl Hanser Verlag, München.

[GEKW12] Gausemeier, J.; Echterhoff, N.; Kokoschka, M.; Wall, M. (2012): Thinking ahead the Future of Additive Manufacturing – Analysis of Promising Industries. Edited by University of Paderborn. Direct Manufacturing Research Center (DMRC). Paderborn. URL https://dmrc.uni-paderborn.de/fileadmin/dmrc/Download/data/DMRC_Studien/DMRC_Study.pdf, retrieved on 21.03.2015.

[Geld14] Geldermann, Jutta (2014): „Leitfaden zur Anwendung von Methoden der multikriteriellen Entscheidungsunterstützung (English: Approach for the application of methods for multi criteria decision support“; Göttingen.

[Goet08] Götze, Uwe (2008): „Investitionsrechnung – Modelle und Analysen zur Beurteilung von Investitionsvorhaben (English: Investment – Models and analyses to assess investments)“; Berlin, Heidelberg: Springer, 6th Edition.

[GRS10] Gibson, Ian, Rosen, David W., Stucker Bren (2010)t: „Additive Manufacturing Technologies: Rapid Prototyping to Direct Digital Manufacturing”; Boston: Springer.

[Grun15] Grund, Maike (2015): „Implementierung von schichtadditiven Fertigungsverfahren – Mit Fallbeispielen aus der Luftfahrtindustrie und Medizintechnik (English: Implementation of AM – Use cases from aerospace and medical engineering)“; Berlin, Heidelberg: Springer.

[Guth14] Guthorn, A.: The Evolving Market in Engine MRO. An Industry Overview, Fort Lauderdale, 2014.

[Hart06] Harth, Micheal (2006): „Multikriterielle Bewertungsverfahren als Beitrag zur Entscheidungsfindung in der Landnutzungsplanung (English: Mulit criteria assessment concepts for the decision making in land planning)“; Saarbrücken: VDM Verlag Dr. Müller.

[Hins12] Hinsch, Martin (2012): Industrielles Luftfahrtmanagement (English: Industrial aviation management), 2nd edition Berlin/Heidelberg: Springer Verlag

[IsNe13] Ishizaka, Alessio; Nemery, Philippe: „Multi-Criteria Decision Analysis – Methods and Soft-ware“; Singapur: Markono Print Media, 2013.

[Lanz11] Lanza, G.; Moser, R.; Ruhrmann, S.; Peter, K. (2011): „Systematisch zum wandlungsfähigen globalen Wertschöpfungsnetzwerk – Ein Ansatz zur Ist-Analyse für die gezielte Integration wandlungsfähiger Strukturen (English: Systematic to a versatile and global value added network)“; in: wt Werkstattstechnik online 101 (2011) No. 4, Düsseldorf: Springer- VDI-Verlag, S. 206-209.

[Laux07] Laux, Helmut (2007): „Entscheidungstheorie (English: Decision theory)“; Berlin: Springer, 7th Edition.

[LHNB14] Lufthansa AG (2014): „Balance – sustainability report for the Lufthansa Group), http://www.lufthansagroup.com/fileadmin/downloads/de/LH-Nachhaltigkeitsbericht-2014.pdf, last retrieved 03.03.2016

[LJM+12] Lindemann, C., Jahnke, U., Moi, M., Koch, R. (2012): Analyzing Product Lifecycle Costs for a Better Understanding of Cost Drivers in Additive Manufacturing, University of Paderborn, proceedings of International Solid Freeform Fabrication Symposium 2012, Austin/Texas.

[LJMK13] Lindemann, C., Jahnke, U., Moi, M., Koch, R. (2013): Impact and Influence Factors of Additive Manufacturing on Product Lifecycle Costs, 24th Annual International Solid Freeform Fabrication Symposium, Austin/Texas.

[Mens11] Mensen, H (2011): Betrieb und Technik von Verkehrsflugzeugen (English: Operation and technis of aircrafts). Berlin, Heidelberg, Springer.

[Mens13a] Mensen, Heinrich (2013): Handbuch der Luftfahrt (English: Aerospace handbook) Heidelberg: Springer Verlag, 2. Auflage.

[Mens13b] Mensen, H (2013): Planung, Anlage und Betrieb von Flugplätzen (English: Planning, layout and operation of airports). Berlin, Springer, 2nd Edition.

[Mich13] Michaels, K.: MRO Market Forecast & Industry Dynamics, Atlanta, 2013.

[ReKo15] T. Reiher, R. Koch. (2015): "FE-Optimization and data handling for Additive Manufacturing of structural parts"; 26th Annual International Solid Freeform Fabrication Symposium / Austin / Texas / USA - 8th-10th August.

[Rep-ol] RepAIR: Future RepAIR and Maintenance for Aerospace industry. URL: http://www.rep-air.eu/

[SGF+08] Spiegel, Hildburg; Götte, Sascha; Friehmelt, Holger (2008): Partnership Supply Chain in der Luftfahrt (English: Partnership supply chain in the aerospace sector). In: Partnership supply chain in der Luftfahrt

[WBM11] Wittmer, Andreas; Bieger, Thomas, Müller, Roland (2011): „Aviation Systems – Management of the Integrated Aviation Value Chain“; Berlin, Heidelberg: Springer, 2011.