Additive Manufacturing in the field of spare parts procurement

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Abstract—Machine-intensive industries (e.g. manufacturing industry) strongly dependent on their spare parts suppliers to keep their business processes running. This dependency leads to an enormous market power on the side of the suppliers whereby very high margins can be achieved. In order to reduce the market power of these suppliers, the application of Additive Manufacturing (AM) technologies comes into play. Nowadays, 3D-printing is rarely utilized within a company's the spare parts management. This circumstance mainly exists because of the fact that the manufacturing companies do not have any idea regarding the technical and economic possibilities (e.g. reduction of procurement time, integration of functions) of this "new" production process. Therefore, this paper is about an overall approach from identifying parts from a stock list (technical and economic characteristics) to the production of a prototype. Furthermore, the different ways of how 3D-printing can successfully be implemented into an organizations business process (BP) are also part of this work.

Keywords—direct metal laser sintering, 3D-printing, additive manufacturing, spare parts management, hybrid manufacturing, sustainability

I. Motivation

Nowadays, industry has reached a high level of efficiency due to sophisticated technology and a high degree of automation. Companies, especially in industrialized countries, are forced to automatize their business processes in order to be competitive on the (global) market. A fundamental requirement to keep these machine-intensive processes running is a cleverly devised maintenance strategy in combination with an efficient spare parts management.

Spare parts, which are counted among the after-market business segment, play a decisive role on both sides of the market. On the buyer side, a basic demand of spare parts is existing due to natural wear and tear which creates a certain dependency on the vendor side. This situation leads to an uneven balance of power on the market which is very profitable for the vendor side due to the high margins that can be achieved. There are even special business models existing which target on the sale or rather on the distribution of spare parts.

Maintenance operations, breakdowns as well as plant downtimes, which always result in financial losses, force companies to ensure that a minimum inventory level of spare parts is always available. This circumstance requires the provision of storage area as well as the provision of financial resources which leads to an increase of a company's working capital.

Womack et al. [1, p. 56] mentioned that Taiichi Ōhno, who was the founder of the Toyota Production System (TPS), states that the provision of inventory represents a nonvalue-adding activity which is equivalent to "waste". This is precisely the point where the concept of Lean Management or rather Lean Production comes into play.

Nicholas [2, p. 3] defines the term Lean Production as follows: "*Lean production is management that focuses the organization on continuously identifying and removing sources of waste so that processes are continuously improved.*"

The possibilities regarding the utilization of optimization principles, such as Lean Management, change from time to time due to the rapid technological progress in this day and age. The industrial application of new generative manufacturing processes in order to reduce "waste" is precisely the point that this work is about.

II. Problem Statement

Among responsible persons in enterprises, there is an uncertainty regarding the economic utilization of three-dimensional printing processes within the field of spare parts procurement. Part of this problem is a lack of know-how regarding the technical producibility of the existing parts via AM processes. Therefore, a classification of the overall spare parts assortment is not possible which is necessary for the investigation of different procurement scenarios.

This current situation implicates that a company's possibilities regarding a cost-oriented spare parts procurement are quite restricted. The consequence out of this circumstance is an involuntary dependency on spare parts suppliers.

III. Research Questions and Objectives

With reference to the problem statement, following research questions are processed within the scope of this work:

- RQ1: What is an adequate method regarding a classification of spare parts with respect to the producibility via AM technologies?
- RQ2: How is it possible to prioritize the classification resulting from RQ1 under consideration of a suitable production process for respective spare parts?
- RQ3: What would be a suitable BP for rational decision-making regarding the sourcing of 3D-printed spare parts based on RQ2?

The paper describes the following research objectives in order to answer those questions:

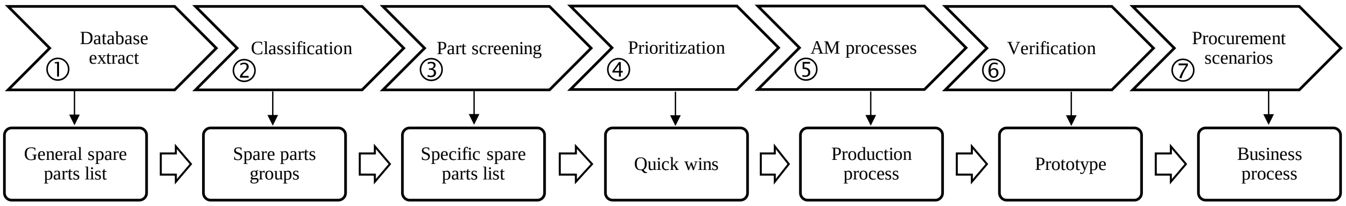

Figure 1: Methodological approach

RO1 describes the development of a method for classifying all the different spare parts regarding their technical properties as well as their economic aspects related to 3D-printing for answering RQ1.

RO2 introduces a prioritization method which is based on the classification of RO1 for different classes of spare parts to answer RQ2.

RO3 declares a BP as part of the spare parts procurement to implement a rational decision-making strategy with respect to 3D-printing of spare parts in order to answer RQ3.

The aim of this work is to determine the technical producibility of spare parts via AM processes within the field of the production industry. The economic feasibility with respect to the different procurement scenarios of spare parts also has to be investigated in order to create an efficient BP.

IV. State of the Art

As Tromans [3, pp. 14-15] describes, Direct Metal Laser Sintering (DMLS), which is also known as Direct Laser Metal Forming (DLMF) or rather Selective Laser Melting (SLM), is an AM technique that has originally been adapted for the production of tool inserts. The DMLS process uses a fiber laser with high power which is directed onto a metal powder bed in order to fuse together the metal particles according to a computer-aided design file. The platform, where the structure is printed onto, is flooded with an inert gas (Argon/Nitrogen) to remove particles that can arise due to the energy input of the laser. During part fabrication, the building platform (powder bed) as well as the powder dispenser platform (powder supply) move by one layer of thickness so that the recoater arm can move without collision.

Kynast et al. [4, pp. 145-146] define hybrid construction as a production process where two different kinds of production technologies interact with each other. In the field of AM, hybrid components consist of a conventionally produced base body on which a functional (complex) geometry is built onto as schematically shown in Figure 2.

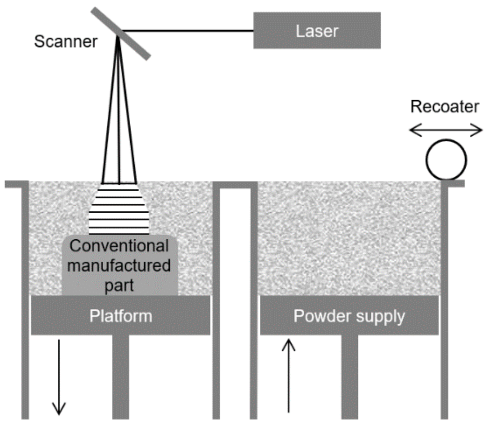

Figure 2: Principle of a hybrid-construction within AM

The principle of Figure 2 is a cost-saving production method due to the fact that the cost advantages of two different processes are combined. Within the field of AM, the production of a part in form of a hybrid construction depends on the overall part geometry. Concerning this matter, the part geometry has to consist of a simple section (traditional manufacturing) and a complex section (AM).

Froes and Boyer [5, pp. 20-21] describe that a large field of application with respect to hybrid AM technologies is repair work, such as geometry restoration or structural integrity restoration. Geometry restoration focuses on the restoration of missing and worn-out geometry of a part, whereas structural integrity restoration is about the restoration as well as the enhancement of the structural integrity of a part which typically involves the repair of cracks and corrosive damage.

Lachmayer et al. [6, p. 121] state that a damaged or rather worn-out part needs to be prepared before the printing process in order to ensure an adequate connection between the part and the repair material. Therefore, the damaged areas of the part have to be removed to create a defined and smooth plane.

V. Methodological Approach

This chapter describes the holistic approach from the investigation of an enterprise’s stock list to the integration of an overall BP that enables the implementation of AM-technologies into an organization’s spare parts management. Figure 1 comprises the sequence of steps of how this approach was executed at a manufacturing company.

Steps 1-4 provide information about the identification and prioritization of spare parts that have potential for AM technologies (technical and economic characteristics). Step 5 and 6 are about the selection of AM processes as well as the prototype production (case study). Step 7 provides insight into different procurement scenarios of spare parts. The single steps of Figure 1 are extensively described from Chapter VI to Chapter VIII.

VI. Potential of Additive Manufacturing

Within this chapter, steps 1-4 of Figure 1 are closely discussed. The first step is about the preparation of a proper database extract. Concerning this matter, the stock list, which includes detailed information regarding every single (spare) part or rather assembly group that is used within the manufacturing company’s facilities, is transferred from an Enterprise Resource Planning (ERP) system into a Microsoft® Excel® list. The result of this first step is a general spare parts list (GSPL) whose key data is shown in Table 1.

Table 1: Key data of the GSPL

Category	**Remark**
Line Items	31,902
Material value [€]	10,501,351.68
ERP system	SAP® SE

With respect to this work, it has to be mentioned that the data quality of the manufacturing company's ERP system is partially inconsistent. The problem related to this circumstance is not only the non-uniform nomenclature, which makes the classification of articles difficult, but also the lack of data regarding base material, unit costs, fundamental dimensions, volume, weight and the information whether it is a standardized part or not. This circumstance leads to a series of assumptions with respect to the technical characteristics as well as the economic aspects (unit costs) of the parts.

Another problem with respect to the data base extract is the fact that there are no parts groups identifiable. This unfavorable circumstance hardly allows any general conclusions regarding the producibility of spare parts via AM. Therefore, under consideration of the large number of line items, a classification of the parts is absolutely essential.

Within the second step, a classification of the parts of the GSPL is executed according to predefined part characteristics. Examples of such characteristics are the types of production systems (e.g. mass production) or the state of aggregation (solid-liquid-gas). The part characteristics of course depend on the respective industry/enterprise. The outcome of this second step is a grouping of the single parts in so-called spare parts groups (SPGs) which comprise electric components (E), standard parts (S), pressurized parts (P), raw material (R), assembly groups (A), individual parts (I) and other materials (O). Table 2 provides an overview of the single SPGs related to their line items and their material value (answer of RQ1).

Table 2: Spare parts groups

SPG	Line items	Material value [€]
I	8,049	3,660,817.82
A	2,937	2,236,769.98
E	5,839	1,900,098.04
S	9,236	1,756,353,54
O	2,317	871,926.28
R	2,462	522,131.41
P	1,062	469,622.39

The third step deals with the part screening and selection methodology. Here, the single SPGs are investigated with respect to their potential for AM (high-level assessment). SPGs, which cannot be economically produced via AM-technologies, are now excluded from further analysis. In this case, only the SPG "individual parts" remained. The result of this step is a specific spare parts list (SSPL) that includes parts that have a potential for AM.

Step 4 is about the prioritization of the parts from the SSPL (low-level assessment). Concerning this matter, every part is individually examined according to certain characteristics that are necessary for the technical and economic assessment. Every part of the SSPL is examined according to the same characteristics.

The quality regarding the results of the technical and economic fit is partially subjective and depends on the expertise of the respective person. On the one hand, this person must have in-depth knowledge about the function of a part/production plant/production process, on the other hand, the person must have expanded skills regarding AM (design guidelines, materials, process). With the help of the information of the SSPL, it is possible to determine the quality requirements (e.g. surface quality, dimensional accuracy), the geometric complexity as well as the pain points ("pain points" is an umbrella-term for all the part properties that cause high manufacturing costs due to enormous complexity and the associated investment in time, such as a large number of work steps or assembly operations of a part.

These characteristics are necessary to classify the part in one category (low – medium – high). Table 3 and

Table 4 illustrate an example of such an assessment including its characteristics.

Table 3: Example of technical fit

Category	**Remark**
Size [mm]	Ø=250, H=28
Material	Stainless steel (1.4542)
Quality requirements	Medium
Additional information	- Conventional design hard to manufacture - Quality issues (weld seams) - Slow time-to-market
Technical fit	**Medium**

Table 4: Example of economic fit

Category	**Remark**
Geometric complexity	Medium
Costs per part	~ 0.3x conventional
Pain points	High
Pain points (details)	- Part consists of many individual components - Many subtractive operations (milling, welding, turning) - Conventional design hard to manufacture - Poor optical appearance
Economic fit	**High**

The results of the technical and economic fit are then combined in the EcoTech Matrix which is shown in Figure 3.

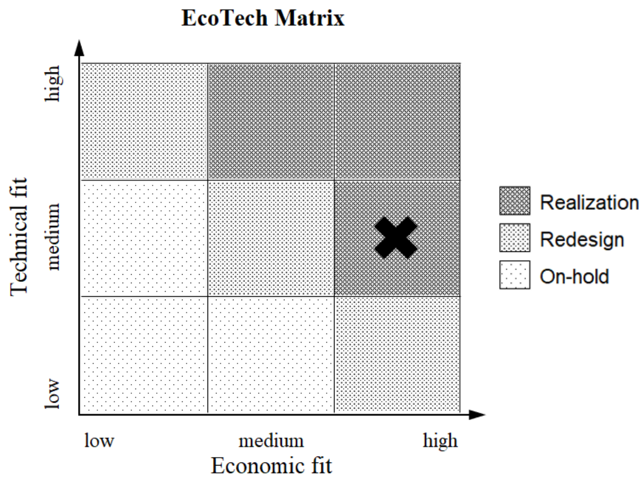

Figure 3: EcoTech Matrix
Source: Schmitz [1]

The EcoTech Matrix again is subdivided into three different sections. Each section stands for a certain priority regarding the realization of the part via AM. The section "Realization" includes parts that can be economically printed without the need for a redesign. The section "Redesign" contains parts that can be economically printed when the part is redesigned. The section "On-hold" includes parts that cannot be economically printed, not even with a redesign. Parts that belong to this section should be reviewed periodically because there is a chance that some of them could move up to a higher section. The possibility for such a change exists because of the fact that the efficiency of AM technologies constantly rises (~factor 8 in the next 5 years).

Within the fourth step of Figure 1, right after the assessment of the EcoTech Matrix, the parts of every section are further prioritized with the help of an ABC-XYZ analysis. The outcome of this fourth step is the final prioritization of the SSPL which is illustrated in Table 5.

Table 5: ABC-XYZ analyses of the different sections

			A	B	C
Priority 1	**Realization**	**X**	Real. AX	Real. BX	Real. CX
		Y	Real. AY	Real. BY	Real. CY
		Z	Real. AZ	Real. BZ	Real. CZ
Priority 2	**Redesign**	**X**	Real. AX	Real. BX	Real. CX
		Y	Real. AY	Real. BY	Real. CY
		Z	Real. AZ	Real. BZ	Real. CZ
Priority 3	**On-Hold**	**X**	Real. AX	Real. BX	Real. CX
		Y	Real. AY	Real. BY	Real. CY
		Z	Real. AZ	Real. BZ	Real. CZ

The processing of the SSPL follows the prioritization of Table 5. Parts of the section "Realization" are processed first (Priority 1), followed by parts of the section "Redesign" (Priority 2) and "On-hold" (Priority 3). The prioritization within a single ABC-XYZ analysis depends on the company due to factors that cannot be generalized (e.g. maintenance strategy) (answer of RQ2).

Subsequently, right after the prioritization, the calculation of the business case follows. Within this step, the production costs of the part with the highest priority according to the EcoTech Matrix are calculated. This calculation includes costs for the creation of the CAD model, the preparation of the part/platform; the printjob, the removal of the part, the removal of support structure, the heat treatment, the surface treatment and the quality check. This cost estimation mounts up to 679.50€. This is about the half of the actual procurement costs which means that the business case is positive.

VII. Case Study – Additive Manufacturing

Within the fifth step of the methodological approach, the production of a prototype is executed in order to verify the technical feasibility. The Concerning this matter, the part is manufactured as a hybrid construction via Direct Metal Laser Sintering (DMLS). The part was printed on an EOS M290 printing system with 1.4542 powder material (stainless steel).

After the prototype production is finished, the exact production costs can be determined according to the data of the printing system (e.g. machine hours). The production costs of the part mount up to 694.05€. (53% lower than the procurement costs of the supplier part). Also, the procurement time was lowered from 70 days (supplier) to 1 day.

VIII. Business Process

Within the last step of the methodological approach of Figure 1, different procurement scenarios are investigated. Depending on a company´s potential for AM (number of parts that are suitable for 3D-printing), a decision between outsourcing and in-house production is possible.

The high-level process structure of Figure 4 constitutes two different kinds of business cases. One business case focuses on process development or rather product

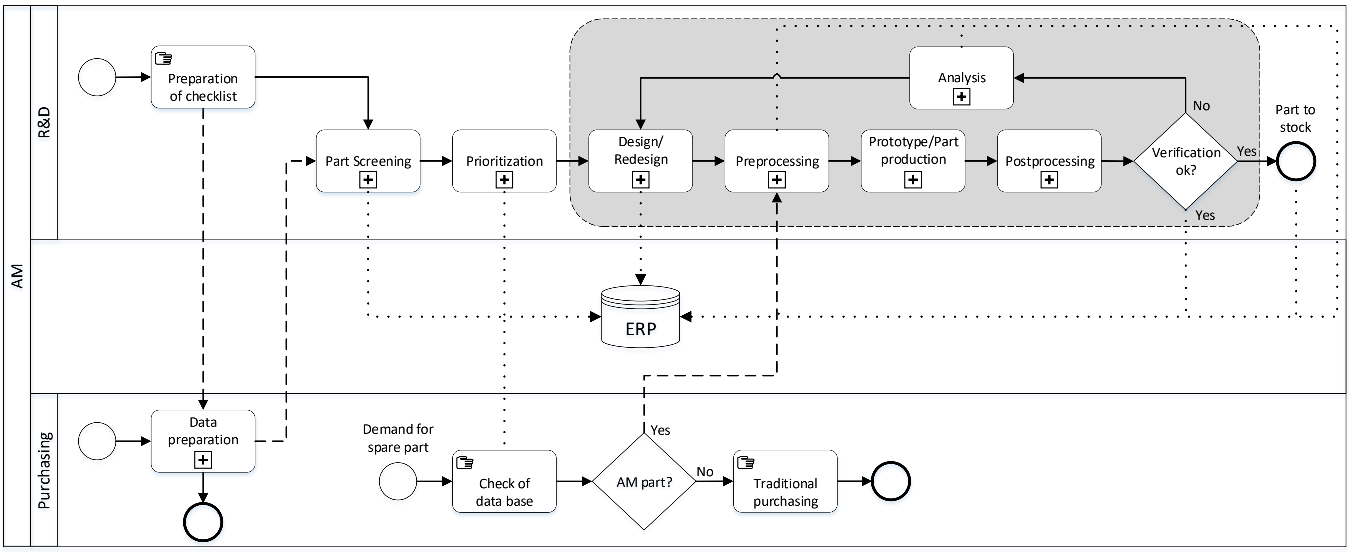

Figure 4: Business process (high-level)

development, the other business case focuses on the fulfilment of demands (=production of already verified spare parts via AM). The business case with respect to the process/product development can be executed internally or externally.

Process/product development: This business case, which is about the development of AM parts, is initiated by the creation of a technical checklist. This task is executed by the R&D department. Subsequently, the checklist is transferred to the purchasing department. Here, on the basis of this checklist, the data preparation is performed. Right after this step, a message is sent to the R&D department which initiates the process of part screening.

Right after that, the results of the part screening procedure are prioritized. The next steps within this high-level process description, which are located within the grey area of Figure 4, represent a group of activities that are targeted on the development or rather on the production of AM parts.

This group of activities represents both, the development of prototypes as well as the production of developed or rather verified parts. The first activity in this group is the creation of three-dimensional CAD models.

After this, the preprocessing work is executed. Concerning this matter, the orientation as well as the support structure of the parts are developed. Subsequently, the production of the part follows. After this step, the postprocessing work is executed. The verification of the printed part, which comes right after the postprocessing work, is an essential step within the overall process. In case that the quality requirements are not fulfilled, the part has to be analyzed in order to find the root cause of the failure. At this point, the previous steps (design - preprocessing – production - postprocessing) have to be re-engineered. In case that the quality requirements are fulfilled, the printed part is placed in stock (or directly installed in the production plant).

Fulfilment of demands: This business case, which is about the production of already developed or rather verified parts, is initiated by the demand for a spare part as shown within Figure 4. Now, within the next step of the process, the responsible person of the purchasing department has to check the data base whether the required part is a verified AM part or not. In case that the part is a verified AM part, the R&D department gets informed regarding the part production. In case that the required part is not a verified AM part, the part has to be purchased from an external supplier on the traditional way.

The BP of Figure 4, which can be integrated in any organization/industry, represents at the same time the answer for RQ3.

IX. Conclusions and Next Steps

The main issue with respect to this work is the uncertainty regarding the producibility of spare parts via AM-technologies. Concerning this matter, the overall approach related to the potential of an existing inventory level of generative manufacturing processes is entirely unclear which is represented by RQ1. This problem is solved due to the systematical categorization of spare parts which is executed on the basis of predefined characteristics. The outcome of this procedure represents seven parts groups of which only one group is suitable for the application of AM.

During the execution of this work, several assumptions were made due to the poor data quality of the ERP system. These assumptions particularly relate to the information with respect to the procurement costs, the fundamental dimensions as well as the base material of the spare parts.

The second issue related to this work, which is represented by RQ2, is about the development of a systematical approach regarding the prioritization of spare parts that are producible via AM technologies.

In the context of the prioritization activities, a suitable spare part was selected as a prototype in order to investigate the technical as well as the economic producibility via three-dimensional printing processes. The prototype, which was built as a hybrid construction, was produced via a printing system for metal powder. The costs with respect to the prototype production (694.05€) were 53% lower than the procurement costs of the original spare part (1.485€).

The third issue within the scope of this work, which is the nescience regarding a systematical integration of AM technologies into an existing business organization, is represented by RQ3. The BP, which is described within Chapter VIII, represents a possible solution of how the application of AM can be implemented in a company's existing process organization. The BP itself, which involves two departments (R&D/Purchasing), includes the development as well as the production of spare parts via AM. The specificity of the BP is the fact that it is applicable for outsourcing as well as for the in-house production of parts. The profitability regarding the in-house production will take longer due to the fact that the production of parts is depending on their development. In turn, a successful development of parts requires specific know-how which cannot be generated over night. Nevertheless, an established in-house production has many advantages over competitors due to the fact that the parts/production facilities can be continuously improved which can have a positive influence on a company's overall performance.

To sum it all up, it can be said that AM technologies can play a decisive role for diverse industries/enterprises, especially when these enterprises source their spare parts from all over the world. With the help of AM, it is not only possible to lower the procurement costs and the procurement time, it is also possible to produce spare parts on a sustainable way. Parts do not have to be shipped all over the planet which has got a big impact on our environment (e.g. reduction of CO_2) and on the overall traffic load. Furthermore, it has to be said that AM is a production process that is economic efficient, regardless where it is deployed. Due to the fact that the AM process costs mainly consist of the system hours, it makes no sense to shift the production to developing countries.

Gebhardt and Hötter [7, p. 400] state that the number of items can be reduced due to the high complexity that can be achieved via AM technologies. The reduction regarding the number of items can have a positive effect on a company's overall performance. The decreasing effort with respect to assembly operations, including the associated problems of adjustment and accuracy, results in lower production costs. Furthermore, the integration of functions often leads to designs that are not possible to manufacture via traditional or rather conventional manufacturing technologies.

Concerning this matter, the analysis regarding the function of parts or rather the interaction of parts with each other would be an interesting and instructive activity based on this work. Such an integration of functions could have several positive effects for a company like for example a reduction of stock items, a reduction of assembly time or an increase of the plant productivity due to the redesign of the parts. Within the execution of this feasibility study, not only the SPG “Individual parts”, but also the SPG “Assembly groups” has to be considered in order to maximize the outcome.

Geroge [8, p. 261] states that a Center of Excellence (CoE) is an uncoupled unit such as a team, an entity or a shared facility that provides leadership, best practice, research and support for a focus area. Concerning this matter, the focus area might be a business concept, a technology, a certain skill or a broad area of study. Furthermore, with the help of a CoE, the revitalization of stalled initiatives may also be aimed.

The establishment of a CoE with respect to AM may have a positive effect not only on the performance of the business partner’s production site, but also on the performance of the overall corporation. Due to the fact that all the sites of the corporation use similar machines or rather production facilities, the potential regarding the application of AM technologies is quite high. The idea behind the CoE is a central production of (spare) parts for various sites of the corporation which are situated within an area that is economically justifiable regarding the transport costs as illustrated within Figure 5.

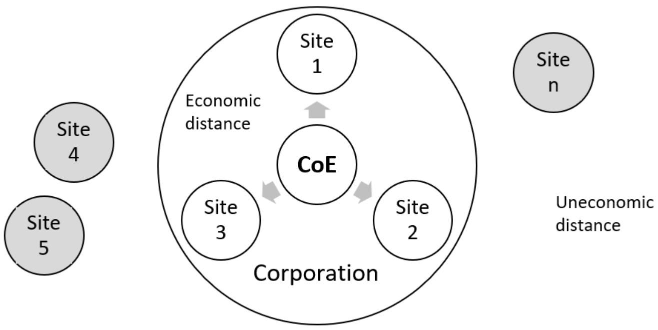

Figure 5: Principle of a CoE strategy

The decision, whether a site gets part of this revolutionary technology network or not, depends on two factors. The first factor represents the potential of spare parts referred to the producibility via AM technologies. The second factor is the geographical distance between the CoE and the respective site. The profitability regarding the CoE strategy of Figure 5, which depends on the relationship of these two factors, is expressed in Formula (1).

$$DC+MC+TC<PC \qquad (1)$$

Formula (1) is an inequation that juxtaposes the costs of a printed part from a service provider with the purchasing costs of the original supplier. Concerning this matter, the development costs (DC), the manufacturing costs (MC) as well as the transportation costs (TC) on the part of the service provider must be lower than the purchasing costs (PC) of the original supplier in order to be economically efficient.

The World Intellectual Property Organization (WIPO) [9, p. 2] states that the subject of IP refers to creations of the mind such as inventions, literary, artistic works, symbols or names and images used in commerce.

Referring to the application of AM technologies, the independent production of industrial parts, which are developed by other companies (suppliers), could be a problem related to the infringement of IP rights. Therefore, the investigation of IP in the field of generative manufactured spare parts for industrial application would be a fascinating subject that could be based on this work.

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