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Evaluation Of Data-Based, Service-Oriented Business Models For Machine Tool Manufacturers

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Abstract

The potential of data utilization in the manufacturing industry enables companies to develop new service offerings for their customers. This creates an opportunity for manufacturers of machine tools and their components to implement innovative, service-oriented business models. These business opportunities can open new sources of revenue and optimize the economic performance of a company. A development of innovative, data-based and service-oriented business approaches involves a number of paradigm shifts for traditionally product-centred machine tool manufacturers. However, a large proportion of companies in the industry only have very limited know-how in data utilization. As a result, most of the projects initiated in the industry to develop data-based service offerings fail. Besides problems with the available database, a lack of understanding of the business approach and a failure to assess the entrepreneurial feasibility of offerings are the main causes of failure. This paper presents an approach to evaluating data-based, service-oriented business models for machine tool manufacturers. Starting with an overview of the state of the art in business models and data-based applications in production, the special features of data-based business models are examined. In doing so, the paradigm shift from an analogue, product-centric to a data-based, service-oriented business model is highlighted. Based on this, requirements for the method are derived and its place in the development process of business models is defined. After a presentation of the developed method, it is finally applied in a practical example of a manufacturer for milling machines.

Keywords

Business Models, Machine Tools; Servicification; Data utilization; Data monetization

1. Introduction

Manufacturing companies are facing a globalized and increasingly dynamic competitive environment. Continuous efforts to optimize internal processes and innovate external service offerings are thus fundamental to keep competitive [1]. Progress in digitalization and data utilization currently leads to a radical change in the manufacturing sector. Numerous efforts in Industry 4.0 show that the use of industrial data offers considerable potential for improvement in a wide range of applications [2]. Data-based business models (DBBM) can exploit these potentials and enable new value propositions with service character [3]. It makes them a central building block for the monetization of an industrial database that is currently largely untapped [4,5]. DBBM have distinctive properties for manufacturing companies compared to established, product-centric business models (BM). A lack of knowledge regarding these differences is a frequent cause of problems in the innovation process [6]. According to recent studies, only few projects to develop data-based offerings lead to a market success for the companies involved [7]. As a result, the spread of DBBM in industry has so far been limited to very few players [8].

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There are numerous obstacles in different fields to the implementation of DBBM for manufacturing companies [4,9,3]. From the point of decision makers in manufacturing companies, however, there is one urgent question in connection with DBBM: How can we generate an added value for our company and our customers with data-based offerings [10]? Accordingly, there is a need for scientific research on the development of suitable methodologies and procedures for the evaluation of DBBM by manufacturing companies in the development phase [9,5,8]. This paper presents a holistic approach for the lifecycle-spreading evaluation of data-based, service-oriented BM in consideration of uncertainties during its development. Its application is finally demonstrated using an example from the machine tool industry.

2. State of the art

2.1 Business models

A BM is a structural representation of the logic by which a company creates value for its customers with a technical solution and sells it to them with the aim of extracting value to optimize its own economic performance [11]. It has overlaps with a company's strategy, which provides input factors for the BM by determining customer groups and competitive differentiating characteristics as well as determining the adaptation of BM alternatives [12,13]. In this context, the term value describes the customer's perceived ability of a technical solution to influence value creation in their own company through its application [14–16]. A customer's perception of value is subjective and depends on their individual situation and objectives [17]. The BM construct is made up of four key components [18]: value proposition, value creation, value creation network and value extraction. The design and composition of these components take place in a BM innovation process [19]. The aim of such a process is to develop new opportunities for value creation in order to increase the economic performance of the operating company [20]. In the course of this process, alternative BM are conceived, designed and evaluated starting from innovation triggers in order to ultimately create a viable and competitive innovation and place it on the market [21,22]. During the process, the maturity level of the considered concepts is increased and their number is continuously reduced through evaluations to a single solution to be pursued [23,24]. The difference between a new BM approach and previous (established) BM is described by the level of innovation [25]. In principle, it can be assumed that the higher the level of innovation of an approach, the greater the uncertainty, interdisciplinarity and interdependence in the innovation process [26].

2.2 Data-based service offerings for machine tool and component manufacturers

The transformation of data into usable insights for customers as part of DBBM follows the steps defined in the data value chain [27]. With regard to companies in the manufacturing industry, the data value chain supplements the traditional, product-centric value chain. Data can be generated in individual stages of the product value chain, which leads to new insights through processing along the data value chain [28]. The implementation of data-based service offerings in industry requires several different capabilities. These include smart products for the collection of data [29], capacities for storage, processing and transmission of data [30,31], methods and tools for data processing [32] and the existence of human-machine interfaces for the presentation of results [33]. The value propositions of a data-based service can be assigned to the categories of descriptive, diagnostic, predictive and prescriptive data analysis as defined in data science. The named approaches provide the customer with answers to "What happened?", "Why did something happen?", "What will happen in the future?" and "What measures should be taken?" [34]. Possible fields of application and potentials can be found in almost all areas of a manufacturing company [8]. An overview of possible applications and their potential for the user can be found in Appendix A1[35–39].

3. Characteristics of data based-business models for manufacturing companies

DBBM are characterized by a creation of value that is largely shaped through the generation, utilization and exploitation of data [3]. In this context, digitized data in various forms is a key resource for generating added value for customers [40,6]. In the context of manufacturing, DBBM have some special features compared to established, predominantly analogue approaches [6]. The following explanations serve to describe these features of DBBM as well as the associated paradigm shifts.

From product- to service-dominant logic: Historically, the BM of industrial companies have been very strongly oriented towards the provision of physical products for their customers. However, there is an increasing trend towards a service-oriented approach to value creation [41]. This development is referred to as servicification [42]. Growing opportunities to use industrial data further reinforce this effect [43]. A key difference between products and services lies in the value-based producer-consumer relationship. In a purely physical product transaction (e.g. sale of a machine tool), a company generates value by providing a physical product, which is then consumed by the customer. In a service business the customer's resources are included in the value creation, which makes him a (partial) producer and consumer of the generated value [44]. According to service-dominant logic, customers' needs consist primarily in the enhancement of resources with which they can efficiently solve a given problem. The customer's needs are therefore addressed in a more targeted manner through concrete solutions in the form of services than through the provision of physical products [45]. Products and services can be combined in various forms as part of DBBM [46]. Such hybrid service bundles are characterized by an integrated and mutually determining combination of products and services [47]. A combination of products and services in DBBM leads to changed conditions for the underlying life cycle model. Specific aspects of physical products, services, software and, where applicable, data analysis models must be taken into account [48]. This results in an increased focus on the usage phase, which is decisive for the creation of value for the customer, the ongoing costs of data utilization and possible revenue streams for the operator of the BM [49–51].

Distributed value creation in company networks: Industrial companies (especially small and medium-sized machine manufacturers) have only limited expertise in the development of data-based service offerings for historical reasons. According to recent studies, a lack of corresponding in-house expertise is one of the biggest obstacles to the implementation of DBBM for industrial companies. This can only be compensated to a limited extent due to a shortage of skilled workers and limited training opportunities for existing staff [5,8]. Cooperations with external companies within an extended value creation network make it possible to close the existing skill gap within a company [52]. Such form of collaboration with external companies can be structured in both short-term relationships at supplier level as well as long-term strategic partnerships [53]. The skills and resources required for the development and operation of industrial, DBBM span various disciplines. These range from domain expertise in the application environment [54] to skills in sensor and electronics development [55], data infrastructure [56], data analysis [32] and software development [48] through to legal expertise [57]. The exact composition and weighting of these always depends on the specific application and can vary accordingly [58].

Intensifying and expanding customer relationships: As already shown, service-oriented value creation in the context of DBBM in industry requires the integration of resources and activities of the customer. The joint value creation requires a deep understanding of the customer's processes [44]. Depending on a customer's individual circumstances, the perceived benefits and costs of consuming the service vary [24]. According to a recent study among digitalization experts, 75 % of respondents consider the understanding of customer needs a critical success factor in the development of DBBM [7]. It is thus important to illustrate the potential added value for a customer through the use of a service offering in a transparent and comprehensible manner [8]. Such a customer-centric mindset is focused on optimizing the customer lifetime value for the operator [59]. Lifetime value refers to the amount of all possible revenues over the period of a business relationship with a customer [60]. This type of consideration is recommended due to the changed nature of business relationships in data-based, service-oriented BM: Due to their service character, they enable a continuity in the exchange of services [44]. The one-off sale of physical products to a customer - as a vehicle for data-based services - is becoming less important. In contrast, the importance of a regular, cooperative generation of benefits for the customer through services is increasing [61]. As a result, the provider takes on some of the customer's process responsibilities [62]. An example of this is the partial takeover of maintenance processes through a data-based application for condition monitoring on a production machine [63]. In this case, the service is continuously provided to the customer and there is continuous interaction via the exchange of data and information [64]. This enables the operator to achieve long-term customer retention and stabilize his revenue streams [65]. It increases the likelihood of cross- and up-selling effects and raises barriers for switching to competitive offerings [66,67].

New pricing strategies and revenue models: The changed form of customer relationships in DBBM requires adjustments to the pricing system [68,69]. It consists of two components: the reference value and the revenue mechanism. The reference value determines the amount to be paid by the customer for the use of a service. It is determined in the pricing process, with various internal and external factors influencing the result [70]. Depending on the operator's efforts and the expected benefit for the customer, a continuum is created in which pricing takes place [71]. Common approaches to pricing can be divided into market-based, cost-based and benefit-based methods [72]. The aforementioned strong customer focus of data-based service offerings is best represented in benefit-based pricing [73]. However, the high degree of individuality of the benefits generated results in increased complexity in their application [74]. The revenue mechanism explains how the fee is billed to the customer [75]. In this context, a shift away from product-centric to usage-centric approaches can be observed. This development addresses the regularity in the exchange of services and possible changes over the course of the customer relationship [76]. Usage-centric revenue mechanisms focus on the usage phase of a service offering and charge directly for the value of data-based services. The customer is billed at regular intervals and the scope can be adapted to the customer's needs over time. A basic distinction can be made between availability-, usage-, result-, and success-based models for usage-based revenue mechanisms. Differences between the approaches arise from technical requirements and the distribution of the economic risk between provider and customer [75].

4. Classification in the innovation process and requirements for the method

The result of the method is intended to provide a basis for decision-making that is comprehensible for decision-makers in manufacturing companies. In this context, a decision-making approach should be based on quantitative factors wherever possible [77]. The method can be used by companies that already have a concrete idea for a DBBM and would like to check its fundamental entrepreneurial viability before further concretizing and transferring it into a resource-intensive technical development project. A preliminary examination of the basic technical and organizational feasibility should already have been carried out and the number of possible BM alternatives should have been reduced using qualitative procedures. At this stage in the development process, it can be assumed that the information required to apply the method is already available at a suitable level of resolution. Consequently, the process of idea generation and design as well as qualitative feasibility checks are not the focus of the method to be developed. Appendix A2 shows a detailed illustration of the classification of the method in the BM development process.

The characteristics of DBBM in the manufacturing environment described above and derived from literature can be used to define content specific requirements for an evaluation method (see Table 1).

Table 1: List of requirements for the evaluation method

Nr.	Requirement (Req.)
R1	The method is applicable for companies with little know-how in data utilization and monetization.

R2	The method considers technical, organizational and personnel requirements of the data value chain.
R3	The method covers all elements of a DBBM including their interactions.
R4	The method is applicable to evaluate approaches with high innovativeness and uncertainties.
R5	The method considers the characteristics of an increased service character of data-based offerings.
R6	The method supports an increased involvement of external partners in the value creation network.
R7	The method supports the evaluation of a continuous exchange of services over the life cycle.
R8	The method supports the integration of changed revenue models and price structures.

5. Conceptual approaches of the method and presentation of the method building blocks

5.1 Conceptual approaches of the method

Based on the characteristics of manufacturing companies and the properties of DBBM in the development process, the design of the method follows four design considerations that are described in the following:

The BM as an investment object: For manufacturing companies, it can be assumed that their primary interest is in optimizing their own profits [77]. It can therefore be expected that the decision to adapt a DBBM in a manufacturing company will be based on monetary criteria [78]. Accordingly, the BM itself can be seen as an investment opportunity for the operating company [79,77]. An investment calculation method is therefore used to combine the cash inflows and outflows obtained in the method modules. Finally, the widespread use in business practice recommends the application of net present value calculation. A positive net present value indicates that the investment is generally beneficial [80]. An absolute representation as net present value enables a comparison with alternative investment options. In the context of manufacturing companies, for example, the expansion of production capacities or the renewal of existing machinery and infrastructure should be considered in this regard [81].

Transformation of qualitative factors: The monetary view only allows for the consideration of factors that can be represented as payments. However, non-monetary factors also influence the benefits of a BM from the operator's perspective. This includes, e.g., a change in the company's image or the customer satisfaction. These qualitative factors can be transformed into quantitative factors via parametrization and additional calculations [82]. By quantifying the factors, integration into the investment calculation and a uniform presentation of results is possible. A description of the transformations to be carried out in the sub-models within the method modules contributes to the comprehensibility of the procedure [77].

Consideration of uncertainties: The evaluation of BM approaches in the development phase is always associated with uncertainties (see Appendix A2) [83,26]. With regard to DBBM in the context of Industry 4.0, there are numerous uncertainty factors that can be divided into business, performance and external uncertainties [84,85]. Accordingly, there is a need to expand the method for fulfilling the postulated requirements (R4 and classification of the method in the development process) to include approaches for taking uncertainties into account [86]. Due to the expected number of uncertain input factors and the associated complexity, a Monte Carlo simulation is used [87,88]. In the case of a DBBM, the simulation consists of calculating different combinations of input factors in a large number of cycles. Combining the individual results produces a probability distribution for the monetary outcome of a business approach. In this context, the following statements can be made on the basis of the result [77]:

- "The investment will yield a positive return with a probability of X %."
- "Taking into account the uncertainty, we expect an average net present value of Y euros."

A disadvantage in this context is the high computing effort, which can be well compensated for by the wide availability of appropriate software (e.g. Oracle Crystal Ball, Python libraries) [89].

Investigation of critical influencing factors: The method is also intended to be a possible starting point for optimizing BM. A sensitivity analysis can be used to examine the responsiveness of generated results to a variation of input factors. The influence of individual factors can be analysed and critical input factors identified [79]. These critical input factors ultimately serve as a reference point for the development of measures to optimize the BM in terms of profitability. Based on the results of the sensitivity analysis, the following questions in particular can be addressed [90]:

- "How does the target function value change for given variations of input variables?"
- "What value may an input variable assume if a specified target function value is to be achieved?"

5.2 Presentation of the method building blocks

The structure of the method is based on the four building blocks of a BM as analytical dimensions and Matzler's model of customer value (see R3) [91]. The building blocks and their content serve to aggregate contents and support the manageability and applicability of the method for users (see R1). Within the building blocks relevant input information is collected and processed using models and tools. The output information generated serves as input information for further building blocks and the final model for value determination of a DBBM. Figure 1 shows an overview of the method structure.

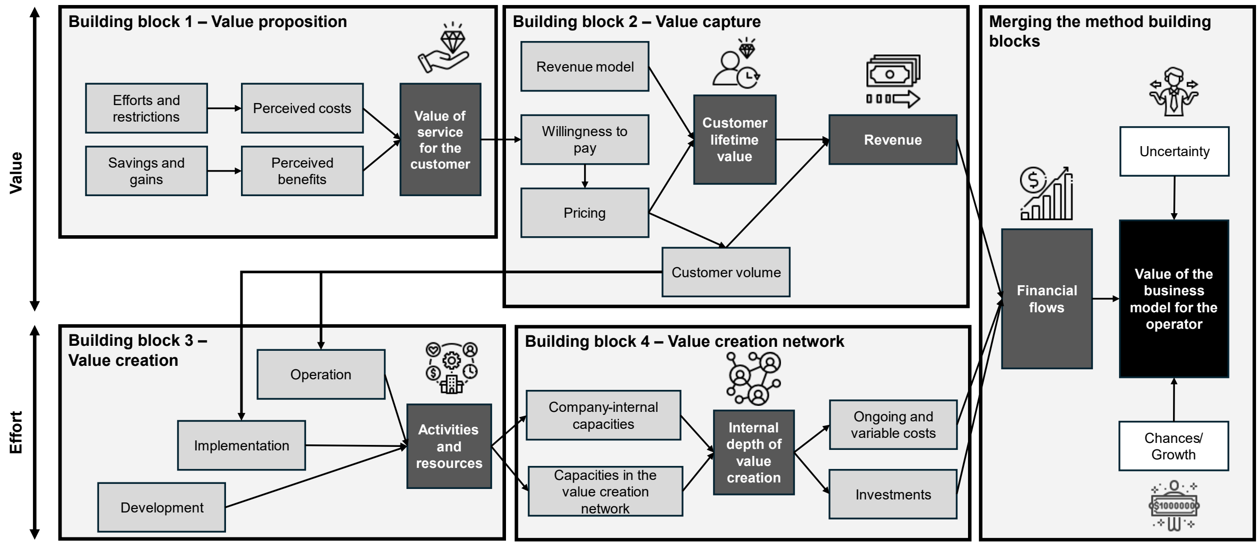

Figure 1: Overview of the evaluation method and its building blocks

Building block 1 - Value proposition: According to the necessity of aligning data-based, service-oriented offerings with the customer, determining customer value forms the initial method module (R5). Customer value - as a key source of information for this block - is derived by comparing the perceived benefits of a service offering with the perceived costs. To determine the perceived benefit, the customer's potential savings and gains from using a data-based service offering are examined. The determination of perceived costs is derived from the structure and scope of possible expenses and restrictions for the customer.

Building block 2 - Value capture: Value capture complements the value proposition regarding the value analysis and forms the second building block of the method. The possible turnover of a business approach results as output information and is used as input information in the final model for value determination from the operator's perspective. The elements of the method module are essentially based on R5, R7 and R8. For implementing the listed requirements, the payment series of the revenue model includes usage-centred approaches with continuous revenue streams are captured. The pricing element is derived from the customer's willingness to pay and influences the development of customer volume over the life cycle of a business case. By combining the value of a customer - as a combination of revenue model and pricing - and the possible number of customers, the revenue is ultimately calculated.

Building block 3 - Value creation: Building block 3 acts as starting point for determining the expenses on part of the operator. R2, R5 and R7 form the central framework conditions for the design of the method module. A consideration of activities and resources in the development, implementation, and operation phases - under the special requirements of data-based value creation - forms the core of value creation. By capturing these three phases, a cross-lifecycle view of the BM is created.

Building block 4 - Value creation network: Building block 4 builds on the findings on the necessary activities and resources and examines the effects of the distribution of these on internal and external company capacities. The elements of the module are derived from R2 and R6. In order to implement these requirements, the outsourcing of activities and resources - particularly data-based activities and resources - to the corporate network is examined. This is in response to the fact that manufacturing companies often do not have their own expertise and resources in the field of data utilization and monetization. According to the resulting breakdown, a subdivision is made into investments as well as ongoing and variable costs. These are then incorporated into the final model to determine the value from the operator's perspective.

6. Application

The method presented was applied within a development process for a data-based service at a manufacturer of milling machines for metalworking. According to its size, the company is a medium-sized enterprise. The existing business activities include the development, production and sale of milling machines and their spare parts as well as physical services in the form of repairs and maintenance activities, among others. Due to increasing competitive and technological pressure, the company aims to expand its portfolio to include data-based services in maintenance. Customer contact in the service department has identified machine spindle failure as a frequent cause of unexpected machine downtimes. The cause of wear is often due to insufficient or incorrect lubrication of the spindle bearings or overloading of the spindle. Together with partner companies, the machine manufacturer has already developed a concept for a condition monitoring solution on machine tools and tested its technical feasibility in a test setup. The partner companies are a manufacturer of machine spindles, a start-up for sensor technology and data evaluation, a developer and producer of IoT devices as well as a provider of cloud solutions.

The evaluation method was applied based on the technical solution approach and an initial concept for the BM submitted by the machine manufacturer. The aim of applying the method was to generate a basis for a decision regarding further investment of resources in the business approach or an adaptation or rejection of the same. Together with a number of representative pilot customers of the machine manufacturer, the potential of the service offering was first determined. Based on historical maintenance data relating to downtimes caused by defects in the machine spindle, the scope of the maximum realizable savings at machine level was calculated. The resulting value was reduced according to the expected inaccuracy of the data-based evaluation to capture the effects of false-positive and -negative statements on the value of the service for the customer. Initial expenses for integrating the solution into the customer's existing systems were also considered. Based on the results of the value of the solution for the customer, the willingness to pay was determined using a choice-based conjoint analysis [92]. The price was finally established based on the revenue model targeted by the company. The hybrid revenue model involves charging an initial purchase price for the retrofitting/equipment of the sensor-based solution and ongoing revenue from the provision of the data-based service. The potential customer volume was determined based on the number of relevant machines in the field and the expected sales volumes of relevant machines in the future. An expert estimate was used to assess an adoption rate for the solution within the market.

On behalf of value creation and the value creation network, various fundamental activities were identified. Firstly, the solution must be further developed to a level of maturity suitable for industrial use, which is associated with initial investment costs by the operator. In addition to the industrialization of the sensor system and further testing, this also includes an integration of the solution into the machine manufacturer's operating system. The provision of IT infrastructure by one of the partners reduces the investment costs for the operator and results in running costs during operation. As with all software and data analysis systems, further ongoing fixed costs are incurred for system maintenance and further development. Different scenarios for their progression along the life cycle were considered. Opportunity costs were also modelled as ongoing costs for the operator, i.e. the lost revenue from maintenance requests in connection with unplanned maintenance for customers of the DBBM. The expenses for equipping machines with necessary technical adaptations depend on customer volume. This includes additional costs for supplied components and sales activities (and, in the case of retrofitting, expenses for installation by technicians). The supplier components in this case are a structurally adapted motor spindle, a sensor bearing including evaluation electronics and an edge device for recording, pre-processing, and communicating the recorded data.

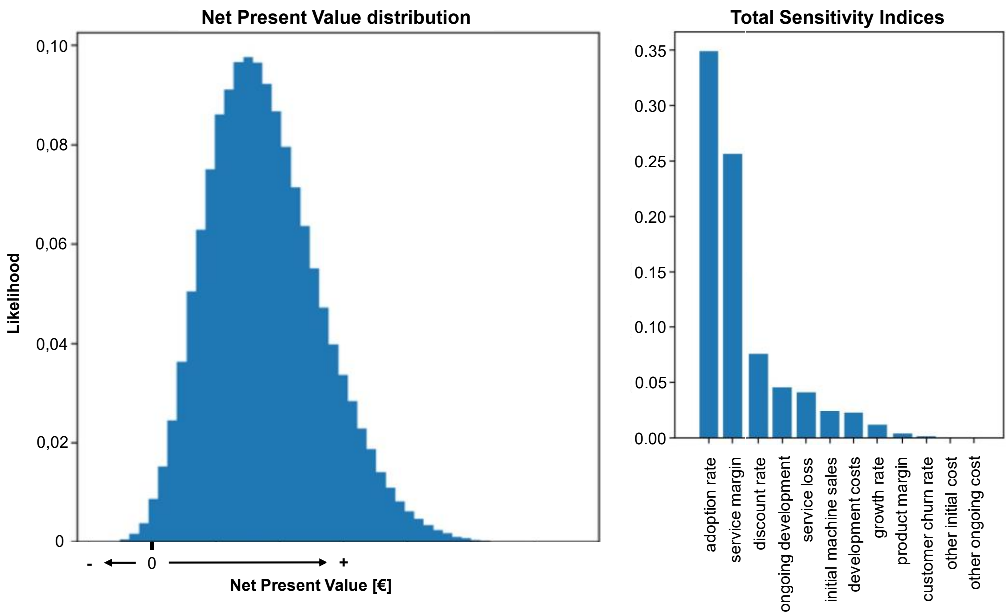

Figure 2: Results of Monte Carlo simulation and sensitivity analysis for the use case

The information collected was ultimately used to carry out a Monte Carlo simulation. The users defined interval limits for the input variables and selected appropriate probability distributions. Figure 2 shows the result of the Monte Carlo simulation performed for the use case. The solution will lead to a positive net present value for the machine manufacturer with a probability of approx. 96 %. The results of the sensitivity analysis show that the adaptation rate and service margin have the greatest influence on the outcome of the BM. Based on these findings, a focus on transparent communication of added value for the customer and sales activities could be derived as measures for further development of the solution.

7. Conclusion and Future Research

In this paper, a methodology for the evaluation of data-based, service-oriented BM in manufacturing companies was derived. Data-based services pose different framework conditions for value creation. Due to these requirements, new approaches are needed for the entrepreneurial evaluation of data-based services. The approach presented addresses this problem by integrating the components of a BM holistically across the life cycle and capturing uncertainties in the development phase using simulative approaches and sensitivity analyses. The application to a use case from the machine tool industry demonstrates its feasibility in industrial practice. A recommendation for future research is to further detail the model as well as the tools used in its building blocks and to test it in further use cases and develop it accordingly. In this way, it may be possible to derive transferable recommendations for the parameterization of BM approaches in the machine tool industry. Furthermore, a comparative analysis with other - especially simulative - approaches for evaluating DBBM should be carried out.

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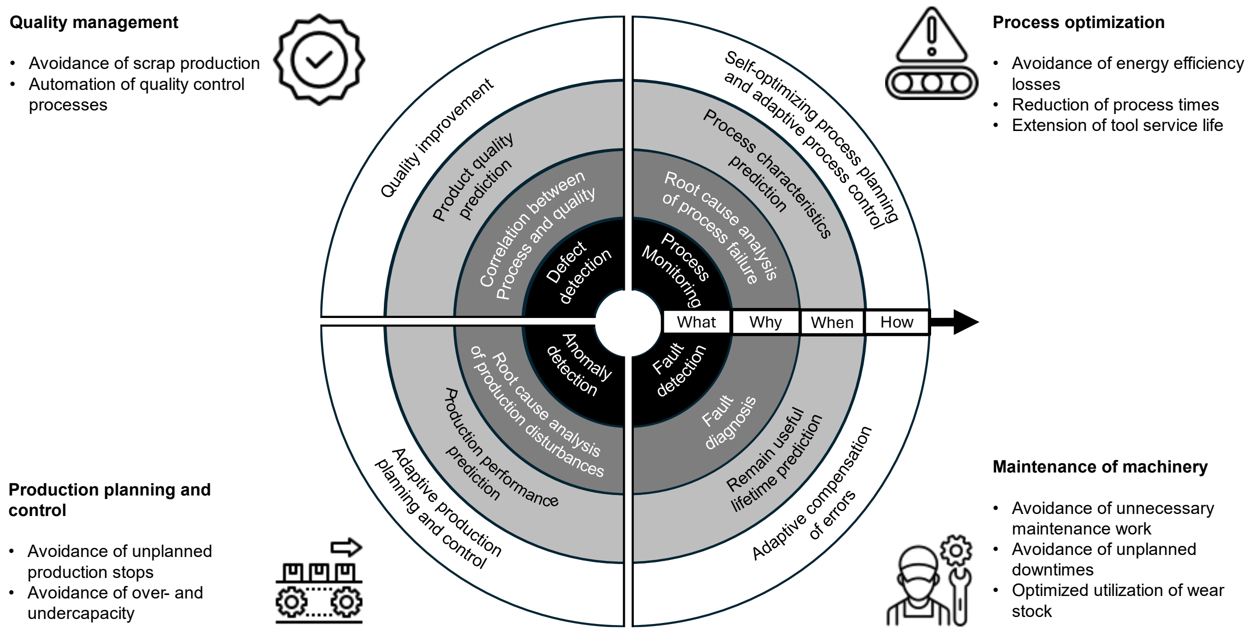
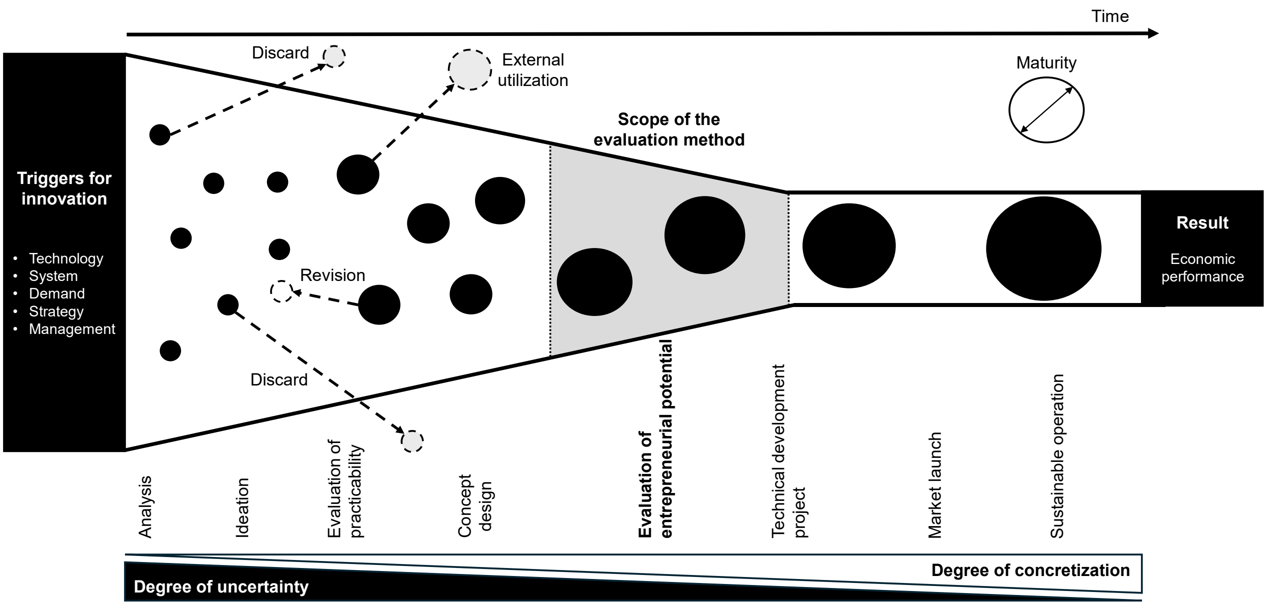
Appendix

A1: Overview of possible applications for data utilization in manufacturing companies based on [35]



A2: Classification of the evaluation method in the BM development process based on [83]



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Biography

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