Lifecycle-based Technology Planning and Assessment of Machine Tools within the Aviation Industry

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Abstract
For various manufacturing technologies such as machine tools, the follow-up costs exceed the acquisition costs after a few years. Currently, there are costs analysis methods, which aim at forecasting the total costs incurred during the complete life-cycle of a given technology. However, these methods do not necessarily lead to an optimal investment decision. Therefore, it is essential to incorporate the expected benefit in the technology investment decision. In collaboration with an industrial partner the IFW developed a method which considers the costs as well as the benefits within the life-cycle of machine tools when making a technology investment decision.

Keywords
Technology assessment, Technology planning, Total Costs and Benefits of Ownership (TCBO)

1 INTRODUCTION
The aerospace is one of the 21st century key industries and a worldwide pioneer in the development and application of new technologies and manufacturing processes [1]. Aircrafts, helicopters, missiles and satellites for civilian and military use, as well as the necessary propulsion systems and workshop facilities, are constantly developed and produced, guaranteeing a myriad of jobs. In Germany alone, over one million jobs depend on the aerospace industry. About 93,000 people are directly employed there, with approximately another 250,000 working within the air traffic and more than 700,000 employed by suppliers. Together they generate an annual sales volume of 23.6 billion Euros. In 2009 the branch invested 4 billion Euros for research and development [2].

To secure the jobs and the overall competitiveness of this industry, it is necessary to ensure a continuous development of the existing technologies and processes for planning and evaluation of manufacturing technologies. Of particular importance, especially for manufacturing companies, is the technology planning for manufacturing technologies such as machine tools [3, 4, 5]. Increasingly, methods for technology assessment are used, which consider not only the acquisition costs but also the follow-up costs. This makes sense because the follow-up costs for machine tools already exceed the acquisition costs after a few years. According to BOCKSKOPF, 60-80% of the machine tool life-cycle costs are caused by the follow-up costs [6].

2 LIFECYCLE-BASED TECHNOLOGY ASSESSMENT
The technology assessment forms the basis of the technology planning. During the technology assessment, an analysis and evaluation of different manufacturing technologies, such as machine tools, is performed. As described above, lifecycle-based technology assessment becomes more and more important, because it records all costs and benefits which appear during the life-cycle of a machine, thus allowing for a holistic approach towards technology planning. The essential lifecycle-based technology assessment methods are presented as follows:

2.1 Methods of lifecycle-based technology assessment
In current research, the two terms Life Cycle Costing (LCC) and Total Cost of Ownership (TCO) are often used synonymously. The overall costs incurred within a life-cycle of a technology are composed of the acquisition costs and all follow-up costs (e.g. maintenance, spare parts, operating costs, etc.).

The most common standards, guidelines and methods for lifecycle-based technology assessment (LCC and TCO) are listed below:

The standard IEC 60300-3-3 ‘Application guide - Life cycle costing’ describes the goals of Life Cycle Costing (LCC), identifies and calculates them and provides examples [7]. Its focus is on costs associated with the reliability of the product, and it is suitable for use by customers (users) as well as manufacturers. This standard defines LCC as ‘cumulative cost of a product throughout its life cycle’ [8].

The VDI-Guideline 2884 ‘Purchase, operating and maintenance of production equipment using Life Cycle Costing (LCC)’ provides a method for performing LCC analysis. This guideline aims at optimising the total costs and benefits of a system as well as the associated activities and processes influencing its life-cycle. It is intended primarily for machine tool operators [9].

The VDMA 34160 is published by the German Engineering Federation and is aimed at machine manufacturers and operators. It describes a machinespecific calculation aid for the prognosis of life-cycle costs. Life cycle costs are defined as ‘the sum of all necessary expenses of a suitably designed machine or equipment from acquisition to disposal’ [10].

The SAE-ARP (The Society of Automotive Engineers Automotive Recommended Practice) 4293 is an U.S.-American norm, which is focused on the aerospace and automotive industry and is an approved branch model. This norm defines the conditions for identifying cost drivers for budgeting, planning, project selection and investment evaluation. A closer inspection of the individual cost elements which influence the LCC allows a powerful application. In addition, various forecasting
techniques (e.g. simulation models) for the determination of these elements are presented [11].

M-TCO (Maintenance-TCO) is a proven method in the automotive industry. On the basis of this method, plant construction firms contractually limit the maximum follow-up costs of a machine which are to be expected by car manufacturers. If the conditions are not held, contractual penalties have to be paid. The details of the calculation method are a subject to confidentiality [12].

The life-cycle model of the company ZF not only optimizes the primary objective of the costs, but also improves the means of production in the long term. This is mainly done through the reduction of unplanned machine downtimes. Basis of this forecast model is VDMA 34160 without the disposal phase, not only because it amounts a very small proportion of the total costs, but also because the residual value of a manufacturing plant is difficult to forecast [13].

2.2 Comparison of the methods

The above-mentioned methods for detecting life-cycle costs of manufacturing technologies are reviewed and illustrated as follows in Figure 1. M-TCO and ZF-LCC are in-house approaches developed in industrial practice. All compared methods possess similarly structured forecast models, but different characteristics regarding the detailing of the life-cycle phases such as acquisition, operating and disposal phase. Major weakness of these methods is that they include only those expenditures which appear within the life-cycle. Moreover, they do not consider the distinctive benefits of different technologies. A sole focus on life-cycle costs may cause wrong decisions, especially for high-tech machine tools [5, 14].

To address this problem, the Institute for Production Engineering and Machine Tools (IFW) has developed the methodology Total Costs and Benefits of Ownership (TCBO) which compares existing costs analysis with the total benefits of an investment. A detailed explanation of this methodology is given in Chapter 5.

3 USAGE SCENARIO FROM THE AVIATION INDUSTRY

To perform a model technology assessment and planning, a usage scenario out of the aviation industry is selected. For the purposes of this task, the cooperation partner has provided the entire manufacturing process of an aircraft structural component. Overall, a portfolio of eleven machine tools with significant investment value is available. Within the usage scenario, the factory with all its machines and equipment is transferred to virtual reality with the help of a simulation model as part of the Digital Factory (see chapter 4). This makes it possible to implement specific product characteristics (e.g. geometric dimensions, volumes, processing times), technological parameters of machine tools (e.g. setup times, processing room, machine utilization) and plant layout (e.g. process chains, storage areas) in the simulation model. In this way, interdependencies of a machine tool throughout the process can be analysed. Thus, a comprehensive evaluation of different approaches and control algorithms is possible without negatively affecting the availability of real manufacturing.

The usage scenario focuses on the metal-cutting manufacturing of milled integral aircraft structure components made of aluminium, titanium and steel. The maximum length of these components is 7.8 meters (25.6 feet).

Various metal-cutting machines can be implemented in the usage scenario. Five-axis, high-performance machining centres for the manufacturing of large structural components are the predominant investments focus within the technology planning. The production of these highly complex aircraft structural components is synchronised with the high safety requirements of the aviation industry. In the following simulation studies, these components (e.g. aeroplane frames) are used as reference components, and all manufacturing steps taken to produce them are implemented as reference process chain (Figure 2). A special feature of the usage scenario is the exceptionally high product variety. Between 1000 and 2000 distinctive geometrical components are produced in small batches. The reference process chain extends from pre-production, over the subsequent metal-cutting machining and deburring up to quality assurance and the surface protection of products. Within the first process chain step, pre-production, large aluminium panels are cut to the rough final shape. In the second step, metal-cutting machining, the structural components are produced near net shape.
adding step is achieved. The available eleven machine tools can be grouped into primary and secondary cost centres. Primary cost centres can be described as manufacturing technologies which process products from raw material (e.g. out of pre-production – factory building 33). Secondary cost centres are manufacturing technologies (e.g. deburring machine, pillar drilling machine) and workplaces (e.g. finishing, quality assurance) which run downstream process steps (out of metal-cutting manufacturing – factory building 8).

4 DIGITAL FACTORY
The usage scenario described above has been converted into a Digital Factory in order to carry out extensive analysis and evaluations without affecting the availability of real production. Additional reasons for the modelling and the approach of the Digital Factory are discussed below.

Modern production systems endeavour to increase product complexity and variety, as well as flexibility and, at the same time, to reduce product life cycles and lot sizes. This also applies to the underlying application scenario from the aviation industry reported in this article. Due to this tendency to shorten product life and planning cycles combined with the more complex socio-technical systems, simple mathematical-analytical methods are no longer sufficient for adequate technology planning and assessment [15, 16]. Within the Digital Factory, a process chain simulation is used. For the creation of this process chain simulation, all relevant manufacturing processes (process chains) are transformed into a virtual reality [17]. This allows analysing and estimating a variety of time- and random-dependent system parameters and would not have been possible using mathematical-analytical methods as they had reached their limits [18, 19].

Due to the described 1000 to 2000 geometrically distinctive products, as well as a variety of available machine tools, an analysis based on mathematical and analytical methods is unfeasible. Therefore, a process chain simulation within the Digital Factory is the logical alternative [20].

The Digital Factory is the virtual image of the real factory. With the help of this tool, processes are simulated and visualised. According to VDI, the term Digital Factory is defined as ‘generic term for a large network of digital models, methods and tools (for e.g. simulation and 3D visualization) which are integrated through a unified data management [21]”. This form of simulation supports strategic planning (e.g. the dimensions of manufacturing capacity and layout analysis) as well as operational planning (e.g. lot sizes, sequencing, optimal response to disturbance events).

The process chain simulation is used to generate a valid database for technology assessment. With the help of the simulation model, different machine tools can be implemented into the usage scenario. By setting the various parameters for the different machine tools, interactions within the whole process chain can be analysed and aspects, such as manufacturing costs, throughput time or busy time, can be quantified (Figure 3). Following, the procedure for determining the TCBO is described.

5 TOTAL COSTS AND BENEFITS OF OWNERSHIP
Total Costs and Benefits of Ownership can be regarded as a method for determination of the price/performance ratio whereby the life-cycle costs (Total Costs of Ownership – TCO) are compared with the benefits of an investment (Total Benefits of Ownership – TBO). The sum of the beneficial effects alone is known as Total Benefits of Ownership (TBO). Beside the costs, now the real benefit effects of a manufacturing technology can be systematically identified, quantified and compared by means of the TCBO-methodology shown in this paper. The term ‘Total Benefits of Ownership (TBO)’ has conceptually emerged as a complementary counterpart to the term ‘Total Costs of Ownership (TCO)’ from the life-cycle model. The ‘Total Benefits of Ownership’ describe a holistic approach that takes into account all positive effects relevant to a company during the life-cycle of an investment. Benchmark for identification and measurement of these effects is the subjective view of the respective enterprise.

By meeting the desired compatibility with the TCO approach and the intended option, to get a statement about economic efficiency through a comparison of TCO
and TBO the proposed approach is based on monetary valuation metrics. Consequently, the identified and categorized benefits are assessed monetarily. This process can be described as the core element of the TCBO-methodology.

The approach developed to gather and evaluate the TCBO is carried out within the following five steps listed below:

1. Identification of benefits.
2. Categorization of benefits in direct, indirect and potential benefits.
4. Comparison of TCO and TBO.
5. Transfer of results, for example, in a technology-roadmap for the definition of the technology planning.

Afterwards, the three benefit-types can then be compared with the costs thus allowing a holistic assessment. The comparison of benefits and costs is executed in three steps:

1. Comparison of direct costs and direct benefits: During this step a comparison of direct costs with direct benefits is carried out. Simultaneous processing (technical efficiency) is an example for direct benefits. Through the simultaneous processing of a work piece by means of two spindles - instead of one - process time can be reduced.

2. Comparison of indirect cost and indirect benefits: In this step an evaluation of indirect costs and indirect benefits is performed. The monetised values have to be added to the direct costs and benefits from the first step, so that the additional effect of indirect effects can be considered. An example for indirect benefit is the economisation of process steps. By using a machine with high quality-level production, the costs for the quality control could be economised.

3. Observance of potential benefits: It is difficult to monetise the potential benefits directly. For this reason, the effects cannot be fully weighted. Using a sensitivity analysis helps to adapt the discount of an effect for every usage scenario. An example for potential benefit is energy efficiency. For example, machine 2 is slightly more expensive than machine 1, but it has a 25% lower power requirement. If the energy prices remained stable, Machine 1 would indeed be more cost-effective. If, however, the energy price increased by 7% per year, like it happened in the period from 2000 till 2007, Machine 2 would prove to be the more profitable.

Based on the comparison between the Total Cost of Ownership (TCO) and the Total Benefits of Ownership (TBO), the TCBO sum is calculated (Figure 4). It makes a statement about the suitability of a technology for the integration into the manufacturing process. The higher the TCBO sum, the better the technology (machine tool).

By linking the TCBO methodology with the Digital Factory, the following aspects can be comprehensively analysed:

1. Manufacturing costs for the products to be manufactured: The manufacturing costs for the evaluated technologies result from the machine hourly rate based on the process and setting-up time of a product.

2. Throughput time for the products to be manufactured: Throughput time is calculated using the NC-Code, which is derived on the basis of component drawings of the products. The resulting identified product-related throughput times are also implemented into the Digital Factory. This makes it possible to analyse the consequences (impact on throughput time and load factor) of new products within the whole manufacturing process.

3. Load factor of machine tools: During the production planning in the usage scenario, a consideration of the load factor of the machine tools is made. This is essentially determined by quantity, process time and setting-up time.

With the help of these aspects, it is possible to make a valid statement about the suitability of a machine tool.
which could be implemented into the process chain of the usage scenario.

6 CONCLUSION
Within this paper, the lifecycle-based technology assessment method ‘Total Costs and Benefits of Ownership (TCBO)’ is presented, which has been realised in the course of the cooperation with an industrial partner from the aviation industry. In order to generate a valid data-base for assessment of machine tools, as well as in order to consider the interactions within the process chain, a simulation model of the Digital Factory is used. The developed and described Digital Factory allows the implementation of different manufacturing technologies into the model and thereby provides a valid data-base for the technology assessment.

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8 REFERENCES


