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Evaluating the value and costs of technology in the manufacturing industry

Janne Mämmelä[1], Tero Juuti[2], Tuomas Korhonen[3], Pasi Julkunen[3], Timo Lehtonen[5], Jarkko Pakkanen[6], Mikko Vanhatalo[7]

[1]*Mechanical Engineering and Industrial Systems, Tampere University of Technology*
janne.mammela@tut.fi
[2]*Mechanical Engineering and Industrial Systems, Tampere University of Technology*
tero.juuti@tut.fi
[3]*Industrial and Information Management, Tampere University of Technology*
tuomas.korhonen@tut.fi
[4]*Rock Drills & Technologies, Sandvik Mining and Construction Oy*
pasi.julkunen@sandvik.com
[5]*Mechanical Engineering and Industrial Systems, Tampere University of Technology*
timo.lehtonen@tut.fi
[6]*Mechanical Engineering and Industrial Systems, Tampere University of Technology*
jarkko.pakkanen@tut.fi
[7]*Mechanical Engineering and Industrial Systems, Tampere University of Technology*
mikko.vanhatalo@tut.fi

Abstract

This paper aims to show the shortcomings of current technology valuation methods and propose a new approach to evaluating the value and costs of technology in the manufacturing industry. It uses dispositional thinking to show the value creation mechanisms of technology, and it uses property-driven development to evaluate the possibilities of technology by examining business and product properties. From the theoretical perspective, the paper uses Design Science, which serves as the basis for understanding technical systems and design processes.

The motivation of this paper stems from practical managerial challenges in the manufacturing industry. New technologies underlie competitiveness and enable disruptive changes. However, systematic ways to evaluate the effects of technology exploitation during the whole product life cycle are scarce. Based on prior literature, an approach that focuses on income is the most recommended monetary technology valuation method. The literature does not describe how in-depth initial knowledge should be collected as a basis for valuation. In prior research, estimations tend to rely purely on the competence of experts, and the valuation of technology can be compared to the valuation of other investments. Such approaches may not take into account the longstanding and ambiguous effects of technology exploitation.

By contrast, this paper shows that a product or concept structure has to be known in sufficient detail to understand the various effects of technology selection. These effects are built upon the fact that all artificial systems that a company realizes through an order-delivery process and that a customer realizes through a technical process are laden with intentions. Such intentions dictate that technology affects a technical system but value is captured within a business system. Therefore, the links between product characteristics and intentions have to be recognized during the product life cycle—from design to manufacturing and use.

Based on the motivation above and a review of the current knowledge, the paper contributes to the literature by presenting a new early-phase technology evaluation approach based on Design Science. This approach is based on a holistic view that requires defining technology, product, and business properties. It evaluates technology properties against product and business properties. By showing the active value creation mechanisms, this approach helps to answer the question of how to use technology efficiently with specific products in a business environment. The proposed approach to evaluate the value and costs of technology supports the development of a new technology valuation method for which this paper proposes a future research agenda.

The existing business and product environment in the industry represents the target application for the approach developed in this paper. Because technology does not have intrinsic value, practitioners and academics alike should consider the specific context of technology exploitation.

Keywords: technology, technology valuation, evaluation, Design Science, Product Design

1 Introduction

New technologies play a major role in the future competitiveness capability of many companies. In the manufacturing industry, there is an ongoing need to evaluate new technologies and their potential. The challenge is to find the most suitable technologies and valuate them correctly to make the right investment decisions.

Technology valuation can be done from many perspectives and for many purposes. The basic reason for valuation is running a business. According to Parr and Smith (2005), technology-based intellectual property valuations are needed in transaction support, licensing, and intercompany transactions. Boer (1999) stated that technology valuation serves as either internal decision support or transaction support. Internal decision support can be used to judge project proposals, and transaction support can be used for the sale of an asset, negotiation of a license, or determining taxes, among others. Current technology valuation methods can be traced to the field of financial management and are based on traditional capital budgeting techniques (Dissel, Probert, & Mitchell, 2008). The school of knowledge management has also influenced the field of technology valuation (Park & Park, 2004).

Prior research has acknowledged that technology decisions are not made in isolation, separately from operations (Aubry, Hobbs, & Thuillier, 2007; Martinsuo & Killen, 2014; Meskendahl, 2010; Mäkinen, Seppänen, & Ortt, 2014). Instead, the value of technology can be realized across a broad range of products because of operational changes that stem from particular technological decisions (Korhonen, Laine, Lyly-Yrjänäinen, & Suomala, 2016; Lyly-Yrjänäinen, 2008). Moreover, technology decisions are made in an environment in which financial values concerning the overall production system can surpass technological values in particular cases (Korhonen et al., 2016; Martinsuo, Suomala, & Kanniainen, 2013).

Technology valuation is understood in this paper as evaluating the monetary sum of the maximum benefits of technology exploitation in the target company. The monetary sum of buying technology (i.e., technology pricing) is beyond the scope of this paper. Terminology is similar to Li and Chen (2006). In this article the definition of technology is according to Hubka and Eder (1988, p. 260): “Specific way of delivering an effect to an operand.” The technical system and product are understood as synonyms.

The technology valuation literature is mostly linked to the topic of intellectual or immaterial property. A limited number of works have focused purely on technology valuation. Parr and Smith (2005) defined intellectual property as referring to patents, trademarks, copyrights, and trade secrets or know-how. They stated that intellectual property and intangible assets do not create value by themselves; rather, those assets are teamed with the business enterprise in which they reside or in which they will be placed for exploitation. Boer (1999) highlighted that the value of technology is situational and that “technology does not have intrinsic value” (p. 75). Valuation can be undertaken in the context of a specific business situation.

Many authors have proposed different classifications of technology valuation methods. This research used the classification by Parr and Smith (2005), who proposed three types of valuation methods: cost approach, market approach, and income approach. These three valuation methods serve as the basis for all other valuation methods and are based on the value of future benefits of asset ownership. The cost approach evaluates the sum of money required to replace the future service capability of the subject property. The market approach seeks the value through a consensus of others have judged it to be. The income-producing capability is used in the income approach to evaluate the value of an asset (Parr & Smith, 2005).

The primary valuation method for technology is the income approach (Boer, 1999; Jang & Lee, 2013; Park & Park, 2004; Parr & Smith, 2005). Technology commercialization is a complex operation, and many variables have to be considered. The income approach with the discounted cash flow method is suitable for evaluating the effects of up-front development costs, timing, and the risk of developing technology. The cost approach does not take into account the earning power of technology. Using the market approach in the case of technology is challenging, since the needed information is rarely available (Parr & Smith, 2005). In many cases, the commercial track record related to technology is missing. Therefore, customary approaches to product or business valuations do not work well in technology valuation (Razgaitis, 2009).

Technology valuation is challenging for several reasons. First, the real benefits of technology are hard to verify because of the complex environment (Park & Park, 2004). Second, valuation is a subjective activity, and value is framed in the eye of the beholder (Boer, 1999). Third, the economic value of technology is realized only after it is commercialized in the market. Few studies have highlighted the importance of combining technology and business (Park & Park, 2004; Schuh, Schubert, & Wellensiek, 2012). Boer (1998) described the pitfalls of technology valuation in the context of free cash flow methods. The basic challenge in current technology valuation methods is that the product is seen as a black box. Actual data related to the product is needed for valuation, but current methods do not define how this information should be gathered. The phases of the product life cycle are also ignored when evaluating the effects of technology exploitation.

Using the income approach to technology valuation requires financial data related to product cost, sales, and timing. In practice, data reliability is based on the assumptions and forecasts of the relevant department. The balance sheet is a collection of costs and therefore cannot take value creation into account. It is hard to understand real value creation mechanisms through backward-looking financial reviews. In addition, combining the strategic aspects of evaluation guided by financial calculations is challenging. The subjectivity of value in technology valuation is easily ignored when the focus is on financial numbers. Concentrating on the monetary aspects in an environment where the correlation of technology and commercial success does not exist can cause errors.

This study uses an approach based on Design Science to open the technical system to the technology evaluation process. According to Hubka and Eder (Hubka & Eder, 1996, p. 73), "The term Design Science is to be understood as a system of logically related knowledge, which should contain and organize the complete knowledge about and for design." The use of an approach based on Design Science stems from the assumption that a product has a significant effect on the value creation and value capture potential of the company. Porter (1985) stated that a company's external conditions define its potential. The resource-based view emphasizes the importance of a firm's personnel (Bowman & Ambrosini, 2000). Stabell and Fjelstad (1998) studied other value creation configurations to understand and analyze firm-level competitiveness.

This research focuses on evaluating the value and costs of technology from the perspective of the company exploiting the technology. We are interested in the information that supports the evaluation process. Therefore, this study aims to answer the following research question (RQ):

> RQ: What information is needed to evaluate the value and costs of technology in the manufacturing industry based on Design Science?

The goal of this research is to investigate the potential of technology in a specific environment with specific limitations given by the company and business environment. The technology transaction method is beyond the scope of this research. The presented approach to technology evaluation can be seen as an integrated approach where both quantitative and qualitative methods are utilized (Dissel et al., 2008). The results of this approach can be used as a basis for more detailed financial calculations such as NPV or Monte Carlo simulations. The approach is highly general; the type, maturity, or business area of the technology do not limit the evaluation.

In this paper, the term "value" refers to both monetary and intangible values. Valuable properties are determined by the business owner and can be converted to monetary estimations based on the best available knowledge. Costs are used to represent monetary costs using the same logic as value.

2 Research process

This study used a constructive research strategy and the Design Research method (DRM). The study is part of comprehensive research project that develops a new technology evaluation method using a Type 3 research project (see Table 1). This type is applicable when the existing design support is insufficient, as in the case of technology valuation (Blessing & Chakrabarti, 2009). The research question was answered in the research clarification and descriptive study 1 phases (Table 1). The complete method will be developed and verified with case study research in a real industry environment in the prescriptive and descriptive study 2 phases.

Table 1. Design research method phases and selected research project type.

	Research Clarification	Descriptive Study 1	Prescriptive Study	Descriptive Study 2
Research Question	x	x		
Type 3	Review based	Review based	Comprehensive	Initial

3 Building blocks from Design Science

In the introduction, we discussed the state of technology valuation approaches and methods. Considering our research question, we will also discuss the key theories in Design Science and what kind of support they can provide for technology evaluation purposes. Artificial systems originate from human needs. Therefore, value cannot be defined in a monetary way in technical systems. A company strategy is commonly related to a specific business segment and business model where the product is a key element. The approach presented in this paper supports linking the strategic aspects to technology through the product. More accurate financial data can be achieved when the product is modeled and evaluated systematically instead of using rough forecasts. Understanding the product also enables the evaluation of the effects of technology on the whole product life cycle, something that is traditionally ignored. Because the market is not stable, pure monetary estimation of benefits can lead to wrong conclusions about technology. Focusing on valuable properties compensates for the market changes.

Based on the aforementioned reasons, we focus on theories in the field of engineering to answer the research question. The Theory of Technical Systems (TTS; (Hubka & Eder, 1988) offers a comprehensive description of technical systems. The other theories presented here were developed based on TTS. Therefore we are using following theories and approach in answering the research question. Systems thinking (Arnold & Wade, 2015) provides the theoretical background for this research. TTS is based on the idea that technical systems can be understood as a specific type of system. The theory of dispositions models and explains the complex relationship between a product and the product life cycle phases. Property-Driven development provides tools for evaluating technology in uncertain circumstances without detailed knowledge.

3.1 Theory of Technical Systems

TTS is a comprehensive and unifying theory of technical systems. All types of man-made artifacts, including products and processes, can be seen as technical systems. TTS is part of Design Science, which describes the elements related to technical systems, the design process, and knowledge about them. The main reason for developing the mentioned theories is the idea that the design can be improved if knowledge of the design process and the objects of design is available (Hubka & Eder, 1988, 1996).

All technical systems are developed to satisfy human needs. TTS uses the transformation process to describe the operand’s change of state to fulfill an intention. Transformation is an artificial process in which changes are achieved through natural phenomena. The theory of properties plays a major role in understanding and developing technical systems. A technical system has properties that cause different behaviors during its life phases. These relationships are also based on natural phenomena and can therefore be designed (Hubka & Eder, 1988). TTS was used to describe the origin and nature of technical systems in this paper.

3.2 Theory of dispositions

Olesen's theory of dispositions was developed with the aim of improving the concurrent development between the product and the relevant production system. According to Olesen (1992), traditional tools and methods were unable to manage the integrated development in the early 1990s when this need appeared. At the center of the theory are the relationships between the product parameters and the parameters of the systems that realize the product and that the product meets during its life. Olesen (1992) defined a disposition as "that part of a decision taken within one functional area which affects the type, content, efficiency or progress of activities within other functional areas" (Olesen, 1992, p. 53).

In this research, the concept of dispositions is understood as an idea for catching and foreseeing the effects of a design decision. Technology enables new design solutions, which can be evaluated through dispositional mechanisms. In this context, dispositions are used to evaluate the effects of technology on the whole product life cycle. Dispositions can be understood as value creation mechanisms.

3.3 Property-driven development

Characteristics-properties modeling (CPM) and property-driven development/design (PDD) are frameworks for delivering explanations of phenomena in product development and design processes. The CPM/PDD framework is not a new method, but it integrates many existing approaches. CPM is the product modeling side, and product development processes are explained by PDD (Chakrabarti & Blessing, 2014).

Weber placed the distinction between product characteristics and properties at the center of the product development process. TTS is the basic theory behind the PDD method. It is possible to define relationships between characteristics and properties based on natural phenomena using synthesis and analysis tools (Weber & Deubel, 2003).

Characteristics refer to the structures, shapes, dimensions, materials, and surfaces of a product. The designer can directly influence the characteristics. Properties describe the product's behavior; the designer cannot directly influence the product behavior but can indirectly influence it by changing the product characteristics. Behaviors such as function, weight, and testability are understood as properties. The design theory and methodology has been using the duality between properties and characteristics for a long time. Author uses different terminology but the idea behind distinction align (Weber, 2012).

This research also uses terms used by Weber. The CPM/PDD approach was applied to model the relationship between product characteristics and properties. The PDD approach was used to evaluate the possible effects of technology; the driver of the process lies in the distinction between actual and wanted properties.

4 Analysis

Our aim was to understand and evaluate the value and costs of technology in the manufacturing industry. The scope of our study is limited to the manufacturing industry, where business goals strongly guide the valuable properties. Because technology itself does not have or create value, we have to understand the context and links between technology and business. This can be done through two different systems: the business system and the technical system. Technology has an effect on the technical system, but evaluation is done in the business system. Generally, the product life cycle involves many parties with their own business systems. Evaluation is done from the perspective of the company exploiting the technology. New technologies do not necessarily have any connection to any business process or value chain, as the technology may have been developed for other purposes. In the case of new technology, the following question often arises: How does the technology fit into our business and product environment? Therefore, the product and business environment should be modeled.

Figure 1 summarizes the key knowledge for evaluating the value and costs of technology, based on the selected literature. The model applies the three key theories discussed in section 3. The content of Figure 1 is explained in greater detail in Sections 4.1–4.4.

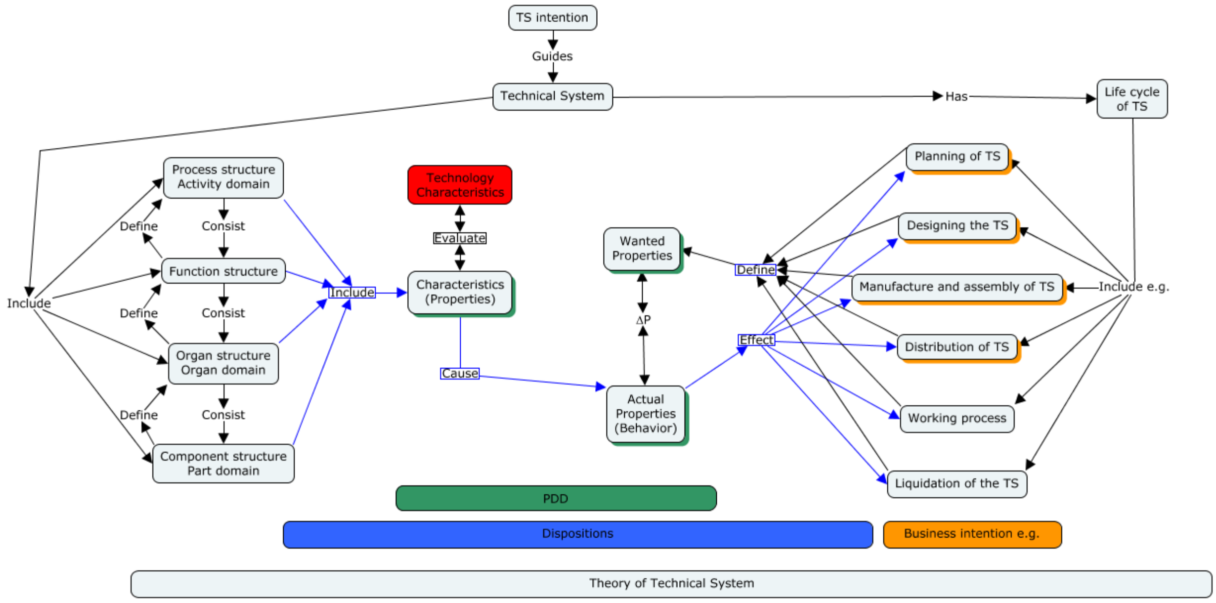

Figure 1. Knowledge required and theories used to evaluate the value and costs of technology in the manufacturing industry, based on Design Science.

4.1 Recognize intentions: Evaluation criteria

Intentions are the evaluation criteria for technology exploitation. Therefore, the definition of intentions, in both the technical system and the business system, is essential. Intentions are commonly linked to and guided by company strategy.

According to TTS (Hubka & Eder, 1988), intentions for technical systems originate from human needs. The main influencer for technical intentions is the product user, but the manufacturer also has an effect through the chosen business segment. For example, the intention of a passenger car is to transport people from place A to B. Humans also operate businesses, and business intentions are fulfilled through the technical system. The business intention for technology can be, for example, to improve profit via the performance upgrade of a product or to decrease manufacturing costs. Intention includes defining which products and business areas are at the center of analysis.

4.2 Recognize properties that create value and costs

Value and costs are mainly results of business deals and contracts. There is no exact correlation between business success and technical properties. The technical system can only produce effects such as material, energy, or information (Hubka & Eder, 1988). Therefore, wanted properties have to be defined according to the previously mentioned classes for technical systems.

TTS states that the technical system has certain life phases. A few of them, such as design and manufacturing, are common to all technical systems. Generally, every product has specific life phases, which have to be recognized for evaluation purposes.

Wanted properties for the technical system are derived from life cycle phases. Properties are results for used process in the life cycle phase. The owner of a life cycle phase has certain needs related to the product. Those needs can be business oriented or softer values. Recognizing those needs and transforming them into measurable properties for technology evaluation is the key to business-oriented technology evaluation. Wanted properties are the target values for the technical system—that is, value capture potential takes place at this point.

4.3 Model dispositions between product characteristics and properties

Technology can make a small modification to a complete product or a significant change to a product function principle. All product characteristics are derived from a product's structure. To understand the product characteristics, it is necessary to recognize the product structure. To support the modeling of product characteristics and properties, we must first define technology characteristics.

New technology is often only an idea or has low maturity when detailed specifications are not available. New product development faces the same challenges. The PDD (Weber & Deubel, 2003) approach supports the evaluation of uncertain solutions. It does not need to know all the details to predict the effects of certain characteristics.

The previous section defined wanted properties. Weber's CPM/PDD approach can visualize the connection between product characteristics and properties. Because of the countless number of characteristics and links, it is not efficient to try modeling all the product characteristics. The target of evaluation is the specific technology that guides the modeling of the product. Links between product characteristics and properties are artificial phenomena. Mentioned connections are also known as dispositions in this paper.

4.4 Evaluate the potential effects of technology

Based on the information from the previous sections, it is possible to evaluate the value and costs of technology in the manufacturing industry. The complete chain of effects from design solution to business criteria is realized. Comparing the characteristics of the technology and the product reveals the potential of specific technology by showing the active value creation mechanisms.

Evaluating the possible change of wanted properties is the key to this approach. We can evaluate and understand what are the potential characteristics where the technology has effect. Following the value creation mechanisms through product characteristics to wanted properties it is possible to evaluate the change of properties that creates value or costs. Based on best available knowledge the change of wanted properties is converted to monetary estimations. To calculate the monetary sum of effects, the real numbers or estimations of volumes, prices, and costs are needed.

5 Results

In this paper, we introduced a new approach to evaluating the value and costs of technology in the manufacturing industry based on Design Science. Main implication of this approach is opening the product and product life cycle phases to the technology evaluation process. The impacts of technology exploitation are evaluated according to recognized value creation mechanisms.

We found eight key elements that must be recognized to evaluate the effects of technology exploitation:

- Technical system intention and business intention
- Product life cycle phases
- Wanted properties from life cycle phases
- Product structure
- Technology characteristics
- Dispositions between product characteristics and wanted properties
- Potential effect of technology related to the product
- Estimation of financial numbers related to the product

This research originates from industry and introduces an approach to support decision making in technology evaluation and investment. An understanding of the dispositions and wanted properties of business supports the identification of suitable technologies in general. Utilizing this approach requires sufficient information on the product and product life cycle. The target group is the existing product and business environment.

6 Discussion

Novelty of this research is opening the product to technology evaluation process and showing the value creation mechanisms of technology. Understanding the product characteristics supports the recognition of the value creation mechanisms of technology, which have not been sufficiently examined in the literature.

Technology choices in the business environment are complex decisions. The approach presented in this paper is based on a literature review in the field of technology valuation and Design Science. The main goal was to support and improve decision making related to technological subjects at the managerial level. Based on the knowledge needed in technology evaluation, the target of technology exploitation is defined and its potential is evaluated through active value creation mechanisms. The selected theories and research method helped in answering the research question and provided a better understanding of the effects of technology in the manufacturing industry. The results are valid mainly at the theoretical level because the research is based on a literature review. Therefore, future research can investigate how this approach works in practice and how the information is gathered in the real industry environment. The approach presented here can be developed toward a new technology valuation method.

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