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Adopting energy flow charts for the economic analysis of process innovations

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Abstract

In many industries, process innovations play a major role in securing long term profitability. Corresponding research and development resources must be used effectively, which requires comprehensive insight into both technological and managerial aspects of the processes concerned. This paper introduces so-called economic flow charts that combine technical and economic approaches and thus provide a means of overcoming communication barriers between engineers and managers. The flow charts illustrate the economic implications of an investment by adopting the widely accepted energy flow charts and by doing so, provide a clear picture of the profitability associated with a process and facilitate the identification of optimization potentials, respectively. An example from the field of biomass-based heat and power production is used to illustrate the economic flow charts' applicability to practical problems.

Keywords: Research and development management; Economic process evaluation; Profit flow chart

1. Introduction

Process innovations not only have a large impact on productivity (Parisi et al., 2006), they also generally play a key role in creating competitive advantage for firms (Cefis and Marsili, 2005). In order to efficiently allocate corresponding research and development (R&D) resources, it is necessary to gain insight into both the underlying (technological) processes and the financial implications of potential modifications. However, multidisciplinary co-operation often lacks efficiency, since the experts involved typically considerably differ in their backgrounds. While engineers have a comprehensive understanding of process details and managers are skilled in financial issues, it is uncommon for persons from these two professions to be (sufficiently) qualified in both fields. Because this knowledge gap causes communication deficiencies (Eppler, 2004) that can result in suboptimal R&D spending, there is a need for a tool that is capable of enhancing mutual understanding and easing interdisciplinary cooperation. To this end, the tool should integrate technological and economic views and, thus, illustrate economic consequences of prospective process alterations. Note that such a tool is not designed to replace the (human) decision maker, but rather to support him/her with respect to the techno-economic assessment of process innovations; additional means may be necessary to adequately capture non-monetary criteria.

In the following, we will introduce so-called economic flow charts (e.g., cost and profit flow charts) which are derived from the widely accepted energy flow charts that are used to visualize energy flows. By supplementing such charts with financial information, it is possible to provide an analogous visualization of the costs and earnings associated with the underlying process. This approach provides a clear picture of the overall process viability, makes the economic evaluation easily comprehensible for engineers, and serves as a means for managers to identify (economically) promising optimization potentials. While our approach originates from analyzing process innovations in the power industry, it obviously can easily be applied in nearly any industrial sector, because activities in other production facilities are structurally comparable with

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energy conversion steps and, furthermore, the engineers involved should be familiar with the functionality of flow charts in general.

This paper proceeds as follows: Section 2 discusses current evaluation techniques for process innovations, while Section 3 is dedicated to deriving cost flow charts from energy flow charts. Section 4 goes on to introduce profit flow charts that extend cost flow charts by also allowing for the integration of earnings and for the dynamic analysis of long-term process innovations. The applicability of our approach to practical problems is illustrated through the analysis of a biomass gasification combined heat and power plant in Section 5. The paper concludes in Section 6.

2. Background

More often than not, process innovations are assessed by their net present values (NPV; cf. Bierman and Smidt, 1993). This approach has become popular in practice because it provides a single indicator for the profitability of an investment. However, the ease of using the NPV comes at the price of condensing all data into a single value and, thus, losing plenty of information in the calculation. For instance, this lost information could involve the smoothness of the flow of returns or liquidity over time that may well be of interest to decision makers, as well as to shareholders and creditors (Ringuest and Graves, 1990). Although most information is available in tables and data sets since it is partly required for calculation, retrieving this information is time consuming and devastates the advantage of having a simple one-figure result. In addition to the partial loss of information details, the NPV approach also cuts the link between the calculation of the results and the subject of the evaluation, i.e., the effects of the process innovation. This does not hinder the simple determination of a process's overall viability, but it will raise a problem when attempting to analyze financial implications of individual process steps.

To overcome these difficulties, researchers have striven for procedures that allow decision makers to determine the economic viability of a process in close interrelation with the technical operation. Since the technical assessment typically follows the process, an economic analysis based on the technical procedure would make the process transparent in terms of its economic ramifications. A highly prominent approach for coupling economic and technical evaluations was developed in the energy industry and is known as thermo-economic evaluation (Tsatsaronis and Moran, 1997), also referred to as exergo-economics or exergy costing (Kim et al., 1998). The main idea of exergo-economic analyses is to use the concept of exergy, an important thermodynamic measure, to determine the economic performance and to measure the increase of value in the course of a production process. As described by the second law of thermodynamics, every process entails irreversibilities, i.e., the degradation of energy resources, leading to an unavoidable level of inefficiency inherent in each process (Hebecker et al., 2005). In order to quantify this effect, exergy was defined as the maximum amount of a stream's energy that can be converted into any other form of energy, notably physical work or electrical power, respectively (Cengel and Boles, 2002). Since the transformation of different forms of energy into electricity is the primary goal of power installations, exergy is a useful measure to describe the conversion efficiency of a process (Dincer and Cengel, 2001). In addition to the inevitable thermodynamically determined inefficiency, exergy is also lost as a result of technical deficiencies (Lozano and Valero, 1993). Because costly fuels such as coal, natural gas or biomass are the main exergy sources in thermal plants, exergy losses beyond the thermodynamic level are disadvantageous not only from a technical, but also from an economic perspective. Quantifying the monetary loss for one unit of exergy lost establishes a link between technical and economic evaluation and affords an opportunity to transition the technical term "exergy" into the financial term "costs". This in turn makes it possible to determine a reasonable investment level by taking into account the trade-off between operating costs and capital expenditures, since process innovations reduce exergy losses (i.e., save fuel costs) and increase the profitability of a process, but often require more expensive equipment (Lazzaretto and Toffolo, 2004; Sciubba, 2001).

The applicability of the exergo-economic approach is limited by the assumption that all costs have their origin in the irreversibility of the process: it is evident that other cost factors besides fuel and capital expenditures, such as labour, administration or planning, must be also taken into consideration and that neglecting these costs embodies the danger of seriously underestimating expenses. A variety of adaptations of the theory have been proposed to overcome this problem. Sciubba (2001), for example, introduced the concept of "extended exergy accounting", which allows for the integration of non-energetic quantities such as labour or environmental costs. However, as the main goal of exergy costing is the translation of a technical term into a monetary one, the question remains why non-exergetic production factors such as labour, for which cost data is readily available, should be first converted into exergy units only to then be re-converted into a cost term using exergy costing.

Another difficulty linked with exergy costing is the high level of technical (i.e., thermodynamic) knowledge that is required to perform such analyses (e.g., Traverso and Massardo, 2002). Despite the interdisciplinary approach, the calculation is unlikely to be easily comprehensible, let alone, practicable for economists. Finally, exergo-economic analyses are only applicable if the processes concerned can be evaluated using the concept of exergy efficiency. While this most often will be the case in the power industry, an exergetic evaluation is not always adequate even for some power industry by-products such as district heat in power plants, because the value of heat does not lie in its exergy. For