Material Flow Cost Accounting – Proposals for Improving the Evaluation of Monetary Effects of Resource Saving Process Designs

R. Sygulla[1], A. Bierer[1], U. Götze[1]

[1]Chair of Management Accounting and Control, Faculty of Economics and Business Administration – Chemnitz University of Technology, Germany

Abstract

There is no doubt about the need for a sustainable production. However, the development of resource saving process designs raises the question how to appraise the economic effects of appropriate alternative process (chain) configurations and technologies. The paper discusses the material flow cost accounting as a potential approach to reveal the quantitative and monetary effects in the frame of material flow management. It gives an introduction to its basic ideas, identifies methodical shortcomings and presents two enhancements for improvement: the explicit regard of energy (loss) flows and a procedure for a more detailed analysis and forecast of system costs.

Keywords:

Material flow cost accounting, Material flow management, Process appraisal

1 INTRODUCTION

The world's material and energy usage, in particular the industrial demand for oil, steel, aluminum etc. has been dramatically increased over the last 30 years and will increase further. Moreover, compared to other cost items (e. g., personnel costs, depreciation) the costs of material and energy use represent – with about 50% – the highest portion of costs in the manufacturing industry. Thus, reducing the use of material and energy will have positive ecological effects like reduced wastes as well as energy losses and may result in material, energy and disposal cost savings. Therefore, it would promote a sustainable economic and environmental management [1].

In the manufacturing industry, the extent of material and energy use as well as material and energy losses mainly depends on the design of the processes which are performed to produce a certain product program. Since a given product program can be manufactured with different process (chain) configurations and technologies, the optimum solution with respect to the pursued targets of high material and energy efficiency and low costs has to be found.

The design of highly integrated process chains with a reduced total energy demand and reduced energy losses (as well as material demand and losses), is also a main target in the eniPROD ('Energy-efficient Product and Process Innovations in Production Engineering') research project [2]. The activities aiming at such process improvements are related to different levels: a single manufacturing step (e. g., a turning process) and combinations of two or more steps up to a process chain covering all required manufacturing activities to produce a certain product (or component). In this context, the research question arises: how to appraise the economic effects of such alternative process chain configurations and technologies? To address this research question, the material flow cost accounting (MFCA) will be discussed as a means to identify and quantify monetary effects of reducing material/energy use and losses.

The remainder of the paper is organized as follows. In section 2, the underlying framework of the material flow management is introduced. Thereafter, in section 3, the material flow cost accounting is presented as a method to overcome the shortcomings of other ecologically and/or economically oriented accounting and evaluation methods. The basic procedure is described and the benefits from the MFCA in the given context are analyzed. Section 4 presents two methodological enhancements of the MFCA approach that aim at improving the appraisal of economic effects of alternative process (chain) configurations and technologies: the modeling of energy use, losses and costs by separated energy flows and the refinement of MFCA costs analysis and planning. The summary and conclusions of the paper are presented in the 5th section.

2 MATERIAL FLOW MANAGEMENT

Material flow management (MFM, sometimes also called flow management) is seen as a holistic, life cycle oriented approach. It supports a targeted, responsible and efficient manipulation of industrial material and energy flows in order to achieve an ecologically and economically efficient use of natural environmental resources including the minimization of relevant emission and waste [3]. In MFM, with a broad view a **material flow** is defined as the 'way' of a material (or an energy) starting with its extraction as a raw material, passing several stages of converting and manufacturing, its use in form of products, possible stages of reuse or recycling, and ending with its disposal. But the management approach also comprises the narrower view of an individual company that strives for reducing its material and energy use and loss by managing and controlling the flow of materials and energy from entering the company up to leaving it as outputs or waste.

As shown in figure 1, MFM can be considered to be a continuous improvement process. In order to ensure directed activities and high quality results, suitable goals have to be identified to guide the improvement processes. Therefore, – like for every management cycle – the initial step of MFM is **goal setting**. Since material flow management is part of a superordinate management concept, the goals of MFM arise from the normative and strategic goals of the company.

The actual MFM cycle starts with **modeling the structure**. In this phase, the system boundaries are defined and the possible 'ways' of all (relevant) materials

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and energies throughout the process chain are identified. On the basis of this information, a flow model is developed. To provide detailed information, the flows have to be differentiated into flows which result in desired goods and flows of material and energy losses (e. g., clippings, chips or waste heat).

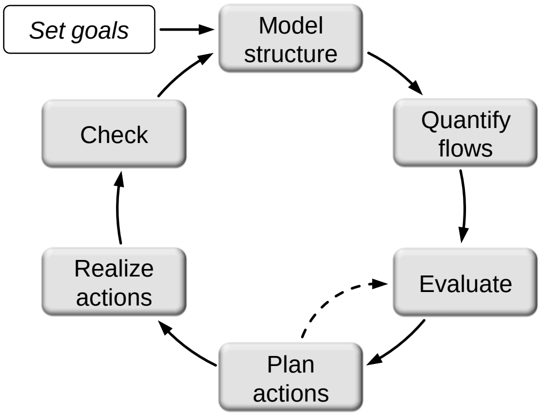

Figure 1: Flow management model.

After the flow structure has been modeled, the **flows are quantified** by measuring the flowed amounts within a defined period. The resulting values are added to the flow model.

In the **evaluation** phase, the as-is state of the flows has to be valued with respect to their resource and cost efficiency. As decisions may concern the design of individual processes as well as of process chains, both are potential objects of evaluation and a methodology is needed that can be applied to both of them.

Based on the evaluation results, specific **actions are planned** (here, alternative manufacturing steps, process configurations and/or technologies) in order to improve the as-is state. To support decision making, the potential impacts of the individual actions on the examined process chain (i.e., the extent of efficiency improvement and the effects on the costs) have also to be evaluated (dashed arrow in figure 1). The potential actions should then be compared among each other and with respect to the as-is state. Thereafter, efficiency improving and cost saving **actions are realized** by implementing specific process configurations and technologies.

A performance **check** analyzes the process chain's new as-is state. This verification will provide information about additional improvement opportunities. Pursuing them or reacting on a change of the underlying goals, initiates new improvement projects, and therewith, new passes of the management cycle.

In the various steps of MFM methodological support is needed. The available approaches mainly differ depending on the underlying goals, the ways of analyzing and evaluating quantified flows and the use of physical and/or monetary evaluation criteria. In the following, several established approaches and their shortcomings with respect to the required needs of a sophisticated evaluation and analysis in MFM will be presented briefly.

The environmental management tool of **Life Cycle Assessment** (see, e. g., [4]) aims at revealing the life cycle-related impacts of products and services on the natural environment. In fact, ecologically intended approaches like this support the reducing of environmental damages. But they do not make clear contributions to cost savings or corporate profits [5].

An economically and flow oriented approach is **Value Stream Mapping** (see, e. g., [6]). Its focus lies on the efficient, customer oriented analysis and design of business processes by preventing non value adding activities (in terms of the approach: 'waste'). Therefore, the analysis of material flows is restricted to a logistic and organizational few. Material and energy losses are largely ignored [5]. A methodological enhancement of value stream mapping by Erlach and Westkämper strives for total energy savings and analyzes every manufacturing step in order to detect energy wastes [7]. This approach is directed at incremental improvements of individual processes, and does therefore not consider effects on other processes or even the internal infrastructure of energy supply. Moreover, the basic approach of Value Stream Mapping and its energy related enhancement do not provide sufficient methodical support for a monetary evaluation of the design alternatives – but, cost appraisals are an essential basis for a meaningful decision making.

However, for the (monetary) evaluations of processes intended here, **traditional cost accounting methods** seem not to be suited very well, too. Commonly, they have a strong departmental orientation and most of the material cost are considered to be direct cost (and therefore, are assigned directly to products). This entails that traditional cost accounting provides only insufficient knowledge about the internal use of materials and energy as well as the manufacturing's material and energy losses.

Environmental cost accounting approaches like the environmentally oriented full cost accounting [8] and waste costing [9] have been developed to overcome the shortcomings of the traditional methods by explicitly integrating economic effects of environmental protection and damage. Partly, they are flow oriented and able to identify and analyze environmental costs and costs of material and material flows, but not in detail. Some cost blocks with high cost-saving potential (packaging, material losses) as well as the energy consumption and the energy losses are still untouched.

In summary, it can be pointed out that the previously presented approaches neglect the complexity of internal material and energy flows. Moreover, they fail to integrate the ecologic and economic dimension of material flow management. The recent approach of material flow cost accounting, which will be examined in the following section, overcomes the mentioned shortcomings, and is therefore more suitable for appraising the benefits of alternative – material and energy saving – process configurations and technologies.

3 MATERIAL FLOW COST ACCOUNTING

Material flow cost accounting (MFCA) aims at supporting material flow oriented analyzes and decision making to improve resource and cost efficiency. It integrates economic and ecological objectives in order to contribute to a reduced or more efficient material use. It is important to note here, that energy flows are usually subsumed under the term of material flows or even neglected (e. g., [10] [11] [12] [13]). In particular, with MFCA it is possible to visualize and quantify material losses and shift them into the focus of the managerial decision making. This is achieved by improving the overall transparency of the material flows in physical and monetary terms [11].

Examples of the implementation of MFCA in practice can be found in Germany and Japan (see, e. g., [5] [14] [15]), where the approach has been developed [5]. Due to the above mentioned focus on material it is in particular suitable for the manufacturing and the process industry. While the number of German examples remains still low, the extensive promotion of MFCA by the Japanese Ministry of Economy, Trade and Industry entailed a more rapid spread [5] (Nakajima mentioned more than 50 Japanese companies in 2004 [13]).

Material flow cost analyzes can be made at different process levels, from individual technical processes or manufacturing steps up to whole value creation chains including several independent companies. Like most of other environmental cost accounting methods, MFCA does not replace the already existing body of cost knowledge from traditional cost accounting methods, but can be understood as a specific partial accounting method to improve economic **and** environmental decision making with respect to material (and energy) usage.

MFCA's general procedure corresponds with some of the steps of flow management: flow structure modeling, quantification of flows, and evaluation (see Figure 1).

Flow structure modeling

In the modeling step, the system boundaries, quantity centers and material flows are identified to set up the material flow model. Figure 2 visualizes the example of a single factory with three intra-company processes. Here, the system boundaries are represented by the factory's property line.

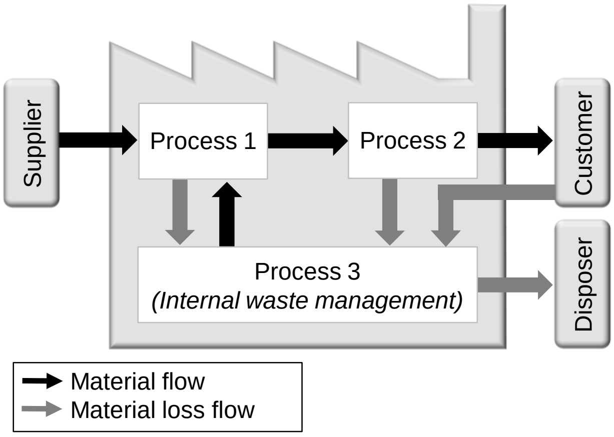

Figure 2: Material flow model (similar to [11]).

Quantity centers (the processes, the external source and the drains in figure 2) are all spatial or physical units handling, processing and/or storing materials. For reasons of simplification, the internal quantity centers might be identical with the existing production cost centers [10] [11]. These are separate accounting units (e. g., a production line, a certain shop floor) with clearly defined responsibilities of a manager for a pool of homogeneous outputs and costs that are incurred for producing these outputs [16] [17].

In MFCA, flows are classified as material flows and material loss flows. Material flows are all movements of a material or groups of materials between various quantity centers that are directed to produce the intended products. Material losses comprise all scheduled (e. g., clippings and chips) and unscheduled (e. g., rejects and outdated or damaged products) losses of the quantity centers [12] [13], even if they are part of internal recycling processes. Figure 2 exemplarily illustrates an internal recycling flow (the internal waste management) and an external recycling flow (a customer returns packaging or used products).

Quantification of material flows

After developing the flow model, the material flows are determined on a quantitative basis. For that purpose, every material movement within an individual quantity center (including changes in the stocks) and between different quantity centers is measured within a defined period. A balance is drawn up to ensure that all material movements are registered. Since usual manufacturing processes are subject to the conservation of masses, the general use of a single mass unit (e. g., kg) is advised for quantification [10] [11]. The collected quantities of the material flows and the quantity center stocks with their initial and end inventory should be integrated into the developed flow model. These quantities can either be visualized by simply transferring their values to the corresponding flows or by using Sankey diagrams (for general methodology and exemplary use see [18]).

Cost appraisals of the quantified flows

The sole accounting of quantities does not provide sufficient support for decision making. Thus, an additional principal item of MFCA is the cost appraisal of the flows which are perceived as cost objects. The so called **flow costs** which have to be assigned to them include all costs which are caused by the flows or which can be related to them [19]. MFCA's recent interpretation by ISO suggests the following major cost items for a categorization of the flow costs [19]:

- **Material costs** are determined by multiplying the physical amount of the particular materials by their specific input prices and summing up the results. The use of fixed input prices allows a consistent appraisal for all manufacturing steps.
- If at all specified, **energy costs** are calculated similar to the material costs. Otherwise, as energy is often subsumed under the term of material, the energy costs are understood as part of the material costs.
- **System costs** are defined as 'all expenses incurred in the course of in-house handling of the material flows except for material costs, energy costs, and waste management costs' [19], e. g., labor, maintenance or transport costs.
- **Waste management costs** are all expenses which occur in the context of handling material losses within a particular quantity center. They are only assigned to the material losses.

The cost assignment – of MFCA as well as of other accounting approaches – differentiates between direct and indirect costs. The direct costs are caused by a particular cost object (in terms of MFCA by a flow) and therefore, can be traced (directly assigned) to it. In contrast, the indirect costs are caused jointly by several cost objects, e. g., the depreciation of a machine which is used for manufacturing several products (see, e. g. [17]). In the context of MFCA, ISO suggests a two step procedure for the allocation (indirect assignment) of indirect costs. First, they are allocated to the quantity centers they can be related to. The sum of indirect costs of a particular quantity center is called the 'quantity center costs'. Second, these quantity center costs have to be allocated to the outgoing flows by using an appropriate criterion [19]; the literature usually suggests the mass ratio of products and material losses [10] [11] [12] [19]. Only ISO at least mentions that other allocation bases are possible, but does not specify any [19].

After the costs are calculated and assigned to the cost objects, the cost flows corresponding to the physical flows can be visualized in the flow model as well. Alternatively, the costs can be displayed using a material flow cost matrix which illustrates the assignment of the different cost items to the products and material losses at the level of individual quantity centers or the whole examined system [11] [19].

The flow cost oriented view on material and material losses regards all costs that are caused over the whole manufacturing process. This allows a first estimation of cost savings achieved by reduction of material losses. But, with respect to the raised research question, the approach has to be extended or refined, respectively.

First, by subsuming energy (loss) flows under the material (loss) flows or neglecting them, the collected data pool does not contain detailed energy related information that enable a company to better understand the magnitude, consequences and drivers of energy consumption and energy losses. Therefore, MFCA does not provide sufficient information to support the analysis of costs and benefits of potential energy saving opportunities. So, the first extension will be the separated consideration of energy flows and energy loss flows.

Second, up to now, MFCA has not been elaborated in-depth with respect to the cost-oriented planning and evaluation of alternative process configurations and technologies. Therefore, section 4.2 introduces a procedure for a more detailed analysis of the system costs and the specific cost drivers determined by the alternatives.

4 EXTENSIONS AND USE CASE

4.1 Modeling energy flows

As mentioned in section 3, MFCA's literature commonly neglects a detailed examination of energy. Exemplarily, Strobel and Redmann state in this context that '[e]nergy flows can be thought of in the same way as material flows, especially since it is often in a material form (in the full sense of word, e. g., coal, oil, gas) that energy first enters a company' [11]. Recent statistics casts this part of their argumentation into doubt. On the one hand, e. g., German industry's primary used energy sources in 2008 were natural gas (27%) and already on the second rank the nonmaterial electricity (22%). In the field of automobile manufacturing electricity was even the most important energy source by far (53%) [20]. On the other hand, in particular, the external sourced electricity is usually transformed before use. Beside the change of voltage and amperage this also includes the conversion to other forms of energy, e. g., compressed air. Thus, the internally used energy can be perceived as an 'intermediate product' and deserves closer attention. For appropriate examinations, the approach of MFCA has to be enhanced by integrating energy flows. In spite of this separated analysis of energy flows and costs, the term 'material' flow cost accounting is kept in the following.

One of the few contributions which regard energy explicitly is the ISO/DIS 14051. It at least recommends to extent the flow model by analyzing energy flows as well, but does not provide any methodological support for this. Instead, the costs of energy are finally still assigned to the outgoing material flows [19]. Thus, there remains the question whether energy flows follow those of outgoing materials and, therefore, could be subsumed under them. However, the simple examples of waste heat or vibration leaving the process as unspecific emissions illustrate the opposite. In this context, the assignment of energy costs to the material flows shifts them off the view of management as it was already criticized for traditional cost accounting's consideration of material.

The improved consideration of energy in MFCA primarily requires a refinement of the flow structure modeling. In order to integrate energy into MFCA's flow model an examination of the physical energy flows on the level of quantity centers is needed. Similar to the input material flow, the incoming energy can be perceived as directed to the function of the quantity center, performing a desired operation. Depending on the specific configuration and technology, a process is characterized by a certain degree of energy efficiency, which determines the parts of effective energy and energy loss. It has to be noted, that the classification as a loss is related to a quantity center and does not include whether their might be recovering processes in following steps.

Figure 3 shows the enhanced MFCA flow model. For the sake of clarity, it neglects the visualization of energy recovery and material recycling. In fact, it shall illustrate a specific characteristic of the energy flows and their modeling: The function of energy conversion processes is to provide input energies for other quantity centers. So, there is a physical energy output flow, which can be modeled just like the material flows. In contrast, the physical energy outputs of manufacturing processes are only energy the energy loss flows. Since the effective energy was used to 'produce' the product (and the material losses) and there is no physical output flow, it has to be interpreted as embodied into the product and the material losses. As a consequence of this, the outgoing material (loss) flows are modeled as joint material and energy flows (the bicolored arrows in Figure 3). They represent energy 'quantity collectors' which sum up the amounts of energy technically required to produce a certain material output.

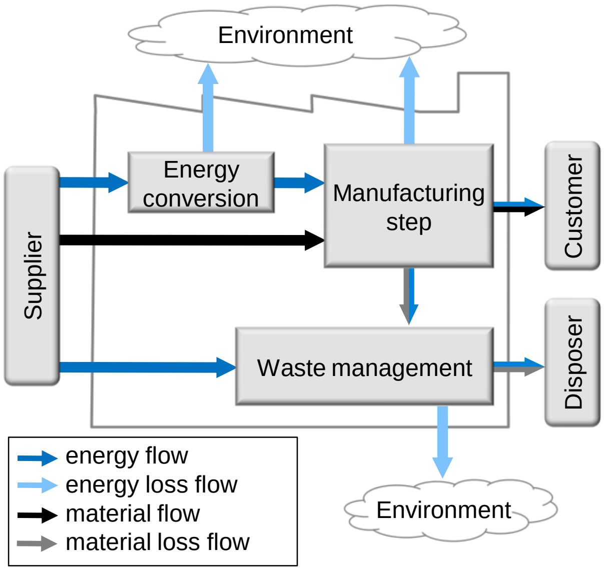

Figure 3: Simplified material and energy flow model

The enhanced MFCA approach supports the appraisal of alternative process configurations and technologies with respect to material **and** energy efficiency. Following the basic MFCA procedure (see section 3), first, the flow structure has to be modeled as described above (separate material and energy flows). Then, both categories of flows have to be determined on a quantitative basis. Finally, the respective flow costs are assigned to the outgoing flows. After the as-is state has been modeled, sophisticated analyses of the flown quantities and the costs can be made. On the one hand, they support the MFM step of planning actions (see section 2). On the other hand, interdependencies of the material and energy use could be identified, e. g., energy savings by reducing the material input.

However, it must be pointed out that feasible benefits of the proposed methodological enhancement depend on the available material and energy related information about flows. But in practice, up to now, especially the energy related information is commonly not recorded in the required level of detail. Thus, additional measurements of the process chain as well as of single manufacturing steps are needed.

4.2 A closer look at system costs

The presented methodology of MFCA (see section 3) commonly aims at a retrospective appraisal of flow systems. The monetary evaluation of flown quantities shall provide information about the **current costs** of losses and, therewith, highlight starting points for improvements [11] [19].

However, in the frame of the MFM (see Figure 1) the evaluation of the as-is state is followed by the step of planning actions (including alternative process configurations and technologies, which are in the focus of this paper). Thus, the intended appraisal of concrete improvement opportunities requires the consideration of **future costs** and, accordingly, a prospective view. ISO notes that the MFCA can also be used for planning purposes, but does not provide any information about useful procedures for cost planning [19].

The implementation of alternative process configurations and technologies (on the process as well as on the process chain level) typically causes significant changes of the underlying flow system. Thus, they influence the major cost items (material, energy, system and waste management costs) in different ways. Especially the system costs seem to be a rather heterogeneous major cost item, resulting from various sub-items that are specifically influenced by the alternative process configurations and technologies. Therefore, a closer look at the system costs and their dependence on the alternative process configurations and technologies is necessary for planning purposes.

To address this problem, the following procedure is suggested – assuming that the amount and types of outgoing desired products do not differ between the alternatives:

- a categorization of the different sub-items of the system costs
- the identification of the cost drivers
- for every alternative: a sophisticated forecast of the various cost sub-items on the basis of the cost drivers.

MFCA literature usually mentions some **sub-items of the system costs** (see, e. g., [5] [10] [11]). In particular, ISO itemizes depreciation, costs of labor, maintenance and transport [19]. However, the categorization should be complete and without redundancy which can be reached by using a classification according to the different input factors like labor, equipment, capital, external services.

These cost sub-items are typically influenced by several – process-dependent – **cost drivers**. For a plain turning process, the several parts of the machining time (primary and secondary processing time, tool change time, set-up time) determine a significant share of the system costs (like labor costs and in some cases depreciation). In turn, they depend on various other technical parameters by themselves. For example,

- the primary processing time is a function of the diameter to reduce and the length to machine as well as of process related parameters as the depth of cut, the feed and the cutting speed [21];
- the set-up time depends on the number of setups which is in turn determined by the product program (types and amounts of the products to be manufactured);
- the available process technologies require different equipment, they (indirectly) determine the depreciation and the cost of capital. So, the alternative process configurations and technologies may be interpreted as cost drivers as well.

These simple examples illustrate, that the system costs depend on a complex network of technical and economical cost drivers, which has to be regarded in the process of cost planning.

Methodological support for the identification and analysis of the cost drivers can be provided by the Input-Throughput-Output-Model (ITO-Model) presented by Götze et al. Beside the recording of in- and outgoing material and energy flows including the loss flows, it aims at the identification of process related drivers of that flows [21].

Using the example of a plain turning process, Götze et al. demonstrated the deduction of an energy cost function which is based on the process related drivers. By extending the view on the other MFCA cost items, the ITO-Model allows examining the causation of costs on a high level of detail (including the technical, process related drivers) and, additionally, regarding the several output flows as well as the specific characteristics of an individual process and the whole process chain. In the given example the several parts of the machining time (primary and secondary processing time, tool change time, set-up time) were already examined separately [21]. Thus, it is concluded here, that the analysis can be focused on the process related drivers of system costs as well.

After the relevant drivers are found, the **system costs** of alternative process configurations and technologies can be **forecast**. First, this requires the specification of the cost driver values of every alternative. Then, the cost sub-items can be forecast on the basis of the relevant cost drivers and the corresponding cost functions. Finally, these costs have to be summed up to the system costs.

Beside the systems costs, the other major cost items are affected by the alternative process configurations and technologies as well. Benefits may result from an increased material and/or energy efficiency. For instance, a reduction of the above mentioned input diameter directly influences the material costs as well as indirectly the energy costs (by reducing the primary processing time). Thus, the other major cost items have to be taken into account in the decision-making process as well. For analysis and forecasting, either similar procedures as for the system costs (for energy and waste management costs) or the existing approaches of MFCA (for material costs) can be used.

The suggested procedure allows it to appraise alternative technologies at a quite high level of detail taking the various cost sub-items and cost drivers into account. At the same time, the main advantage of MFCA, the high transparency concerning material, energy and loss flows, is kept, enabling among others the identification of further improvement potentials.

However, the final criterion for the comparison of given alternatives can only be the total costs. In this context the question arises, how to deal with several cost drivers (e. g., in case of comparing alternative technologies) and – in general – with different levels of uncertainty of data. A meaningful decision making should take into account the quality of the forecasted results (e. g., with respect to accuracy, completeness, and robustness). In this context, it has to be noted that the quality of the results and the low costs of the analysis are rival goals. In practice, it has to be found a trade-off between the goals by choosing the appropriate level of detail of data collection.

5 SUMMARY AND OUTLOOK

The paper described the material flow cost accounting as an approach to support the appraisal of alternative process chain configurations and technologies aiming at improving material and energy efficiency of individual manufacturing steps as well as the whole process chain.

On the one hand, it has been pointed out that the MFCA approach is able to provide detailed information enabling a company to attain a higher transparency of material usage and losses as well as to identify opportunities for an increased performance of its manufacturing processes. On the other hand, methodological extensions have been suggested aiming at an improved evaluation of resource and cost efficient process configurations and technologies: the integration of energy flows and energy loss flows into MFCA´s flow model and a more sophisticated analysis and forecasting of system costs under the consideration of cost sub-items and cost drivers.

Further research activities are needed in at least three fields: First, a more detailed methodological elaboration and practical validation of the described enhancements are required. Second, further refinements of the MFCA approach should be developed to fully meet the life cycle orientation of the MFM concept and to support long-term decision-making. Finally, a stronger integration of the MFCA and the traditional (German) cost accounting is needed in order to lower barriers of adoption (see [5]) and to ensure a continuous use.

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