Material Flow Cost Accounting with Umberto®

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Abstract

Transparency and evaluation of material and energy flows are preconditions for an effective increase of material and energy efficiency. To accomplish this, Material Flow Cost Accounting has been developed and recently been elaborated within DIN EN ISO 14051: 2011. This paper addresses the IT support for Material Flow Cost Accounting by discussing the potentials and possible refinements of the IT tool Umberto®. For illustration, the case study of an extrusion recipient is taken from the collaborative research centre SFB 692.

Keywords:

Material Flow Cost Accounting, Umberto, recipient manufacturing

1 Introduction

Material costs often represent a large part of costs in industrial enterprises and, thus, for companies it is necessary to focus on material efficiency in order to save materials and material costs. This can be achieved by reducing necessary material input and/or waste – based on new product or package designs, optimised production techniques and organisational measures – or by recycling. A precondition for enhancing material efficiency is a high transparency of material flows within or even across companies and the corresponding material costs. To accomplish this, Material Flow Cost Accounting (MFCA) has been developed [1-4]. Although the focus is on material, MFCA also applies to energy (consumption) to some extent and may be further enhanced to an instrument that is useful for an integrated analysis of material and energy flows and the corresponding costs [5, 6].

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This paper deals with the IT support for MFCA. Results of literature review showed that up to now no software solutions specialised on MFCA exist. Thus, it is analysed how MFCA can be implemented within an IT tool – Umberto® – that is originally intended to support the modelling of material flows and life cycle assessment. To illustrate the implementation, the case study of an extrusion recipient is taken from the collaborative research centre SFB 692 – High-strength aluminium-based lightweight materials for safety components (HALS), funded by the Deutsche Forschungsgemeinschaft. To provide a basis for this, chapter 2 gives an overview of the development and the objective of MFCA. In chapter 3, the procedure of MFCA will be exposed, mainly focusing on DIN EN ISO 14051: 2011. Based on this, the implementation of MFCA within Umberto® is analysed in chapter 4. Finally, potentials and possible refinements of the software are summarised in chapter 5.

2 Development and Objective of Material Flow Cost Accounting

Material flows always have been an object of industrial management [7, 8].[1] However, boosted scientific discussions about material flows and waste as well as sustainability thrived on the increasing demands on environmental protection and the rising material costs in the 1990s. The *development* of first approaches using the term „Flow Cost Accounting“ [1, 3, 10] can be attributed to the "Institut für Management und Umwelt", Augsburg, Germany [11, 12]. International attention of (Material) Flow Cost Accounting was enhanced by published case studies of the Japanese Ministry of Economy, Trade and Industry (METI) [13]. The endeavours in Japan also had pushed the development of the ISO 14051, which was recognised by the European Committee for Standardization and by the German Institute for Standardization, Deutsches Institut für Normung (DIN), in line with the DIN EN ISO 14051: 2011 [4, 14].

Like related material and energy flow-oriented approaches of Environmental Cost Accounting (Waste Costing, Materials-only-Costing and Lean and Green Supply Chain Management), the (Material) Flow Cost Accounting brings material flows (and partly also energy flows) into the spotlight of cost analysis [2, 15]. According to DIN EN ISO 14051: 2011, the *objective* of Material Flow Cost Accounting is “to motivate and support the efforts of organisations to enhance both environmental and financial performance through improved material and energy use” [4] by means of:

[1] A relatively early comprehensive analysis of material flows and material costs within the chemical industry comes from Steuer [9].

- improving the transparency of material flows and energy consumptions as well as related costs and environmental aspects,
- support of decisions within organisations in fields of process technology, production planning, quality management and supply chain management as well as
- improving the coordination and communication regarding material as well as energy consumptions within the organisation.

MFCA was developed because the potential of *conventional cost accounting* regarding the transparency of material (and energy) flows, the support of related decisions and the improvement of material and energy efficiency is quite limited: Within conventional cost accounting costs of material and energy losses are usually not calculated, and because at least material costs can be directly allocated to products, they often bypass cost centres and therefore the pressure to reduce them [16, 11]. However, conventional cost accounting can serve as a data pool for MFCA and MFCA can be seen as a replenishment of conventional cost accounting and other instruments like Activity Based Costing [16, 29].

3 Procedure of Material Flow Cost Accounting

The general procedure of MFCA consists of three steps: flow structure modelling, quantification of flows and evaluation (cost appraisals of the quantified flows) [5]. DIN EN ISO 14051: 2011 embeds these steps in a Plan-Do-Check-Act-Cycle for the implementation of MFCA (figure 1).

The *involvement of management* and the *determination of necessary expertise* can be seen as initial key steps within the PLAN module, which help to create a base of acceptance and availability of skills for further steps of implementation of MFCA. The next two steps of the PLAN module are parts of flow structure modelling.

Flow structure modelling

For the modelling of material and energy flows *system boundaries* have to be *specified*. Basically, the boundaries can span a single or several process(es), the whole organisation or even entire supply chains [4]. As a base for structured analysis the decomposition into subsystems might be useful [17]. Furthermore, the specification of a *time period* is necessary. For getting significant data, the time period should be sufficiently long. Thus, seasonal fluctuations and inherent process variations can be recognised and factored in interpretations of data. Time period can be, for example, a month or a year or the time which is needed for the manufacturing of a production lot [4]. The final planning step within PDCA-Cycle is the *determination of quantity centres*. According to Strobel [16], quantity centres are spatial or functional units which store, process or otherwise transform materials (such as material storages, production units, outgoing good storages or disposal systems) and which are connected by material flows. Extending this interpretation to some degree, DIN EN ISO 14051: 2011 determines that *processes,* such as receiving, cutting, assembling, heating and packing, can be defined as quantity centres as well as material storages. METI also refers to processes, sees quantity centres as "theoretical units of MFCA calculation" and points up that all loss-causing points theoretically could be defined as quantity centres [11]. Flow structure modelling reaches beyond the PLAN module of PDCA. As the first "DO"-step, for each quantity centre *inputs* (e. g. materials, energy) *and outputs* (products, material and energy losses) have to be *identified.*

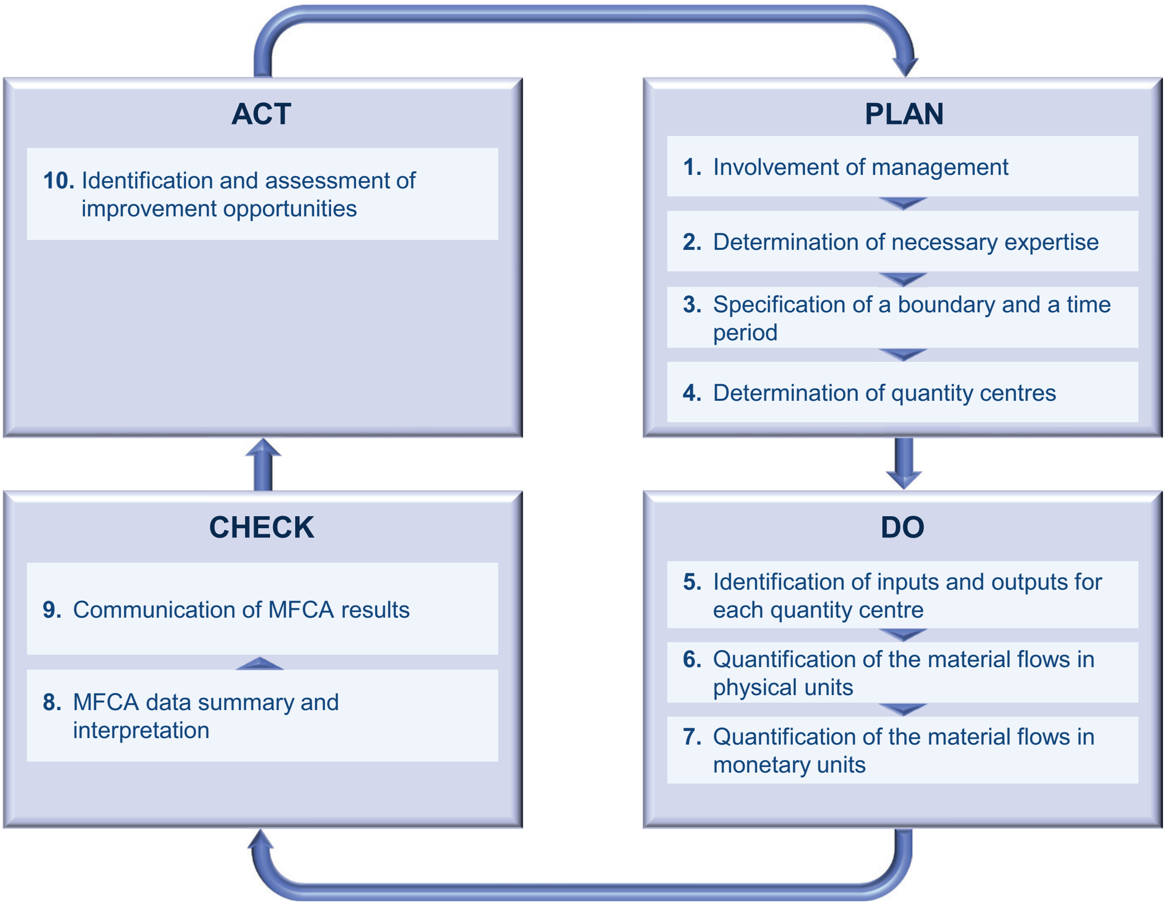

Figure 1: Plan-Do-Check-Act-Cycle for Implementation of Material Flow Cost Accounting [4]

Quantification of material flows

The quantification of material flows is the second step of the DO module of DIN EN ISO 14051: 2011. Based on the flow structure, material flows have to be *quantified in physical units* such as mass, length, volume or number of pieces. By using a single standardised unit (e. g. mass), for every quantity centre a material balance can be created [4].

Evaluation of material flows

Within the last step of the DO module, material flows are quantified in terms of monetary units (as so-called flow costs) in order to evaluate them. DIN EN ISO 14051: 2011 differentiates between material, energy, system and waste management costs [similar to 11, 18, 19, 20]:

- *Material costs* have to be calculated "for a substance that enters and/or leaves a quantity centre" [4] and, thus, for products as well as for material losses.
- *Energy costs* are costs for electricity, fuels, steam, heat, compressed air and others. They should be calculated for each quantity centre on the basis of the measured or estimated energy use. If energy use cannot be measured or estimated for individual quantity centres, total energy use can be allocated to the (output of) quantity centres on base of the mass criterion for means of simplification [4].
- *System costs* represent all costs for handling in-house material flows except for material costs, energy costs and waste management costs [4]. For example, this includes costs of labour, depreciation, maintenance and transportation. In the case that system costs cannot be calculated for single quantity centres but only for superordinate organisational units, they could be allocated on the basis of suitable criteria such as machine hours, production volume, number of employees, or floor space [4]. Furthermore, they should be allocated to products and material losses by again using appropriate criteria, which can be different for each type of costs. Simplifying, the mass criterion can be used again (for a closer look at system costs see [5]).
- Finally, *waste management costs* are costs "of handling material losses generated in a quantity centre" [4]. Waste management includes the management of air emissions, wastewater and solid waste. Waste management costs are costs for internally [29] or externally executing activities like reworking of rejected products, recycling, waste tracking, storage, treatment or disposal [4]. Normally, they are allocated only to material losses.

The CHECK step of the PDCA-cycle concludes the *MFCA data summary and interpretation*, e. g. using material balances, material flow cost matrices or Sankey diagrams (see chapter 4), and the *communication of MFCA results*.

Based on the created transparency of material and energy flows, finally, *improvement opportunities* for reducing wastage have to be *identified and assessed* within the ACT phase and decisions have to be made before the cycle starts again.

MFCA is quite a “young” instrument. On the one hand, its potential is obvious, on the other hand some methodological shortcomings have to be noted: They concern, beside others, the substantiated analysis of system costs and costs of storages, the inclusion of energy flows, the forecast of flow costs, and the integration with life cycle costing. However, this paper is not intended to deal with these issues. Instead, the support of MFCA by a selected IT tool will be discussed in the next chapter.

4 Using Umberto® for Material Flow Cost Accounting

4.1 Overview

IT tools for a comprehensive support of Material Flow Cost Accounting are supposed to enable both the modelling of material (and energy) flows and the evaluation of the quantified flows. For modelling material flows several IT tools had been developed, for example Aspen Plus® and Umberto®.[2] Since Aspen Plus® is focused on chemical processes, Umberto® was chosen for analysis. Besides its flow modelling module, Umberto® provides a cost accounting module. Thus, the question arises how and to what extent a MFCA according to DIN EN ISO 14051: 2011 can be performed by this cost accounting tool (in Umberto® 5.6).

Umberto®'s potential for MFCA will be described and analysed similar to chapter 3/ DIN EN ISO 14051: 2011 regarding:[3]

- Flow structure modelling
- Quantification of material flows
- Evaluation of material flows

For illustration, the example of an extrusion recipient is used. An extrusion recipient (figure 2(a)), in this case, is a tool for the extrusion (figure 2(b)) of aluminium billets into specific profiles, which are processed within the automobile industry, for example. This tool often consists of three components: liner, liner holder and mantle

[2] For an overview of Flow Management and Life Cycle Assessment Software for enterprises see [34, 35]. For using Enterprise Resource Planning Systems for Material Flow Management see [20, 21].

[3] Concerning former analysis of Umberto® regarding Life Cycle Assessment and related areas see [22]. Umberto® was the result of a joint development project of the Institute for Energy and Environmental Research Heidelberg (Institut für Energie- und Umweltforschung Heidelberg, ifeu) and the Institute for environmental informatics Hamburg (Institut für Umweltinformatik Hamburg, ifu) [22] and had been conceptualised for Life Cycle Assessment. In 1998, a cost accounting component was integrated in Umberto® 3.0 [23].

[24]. All these components have to pass through the manufacturing steps of drilling, preprocessing, tempering and finish-turn before they are joined by shrink-fitting. This can be visualised by material flow models.

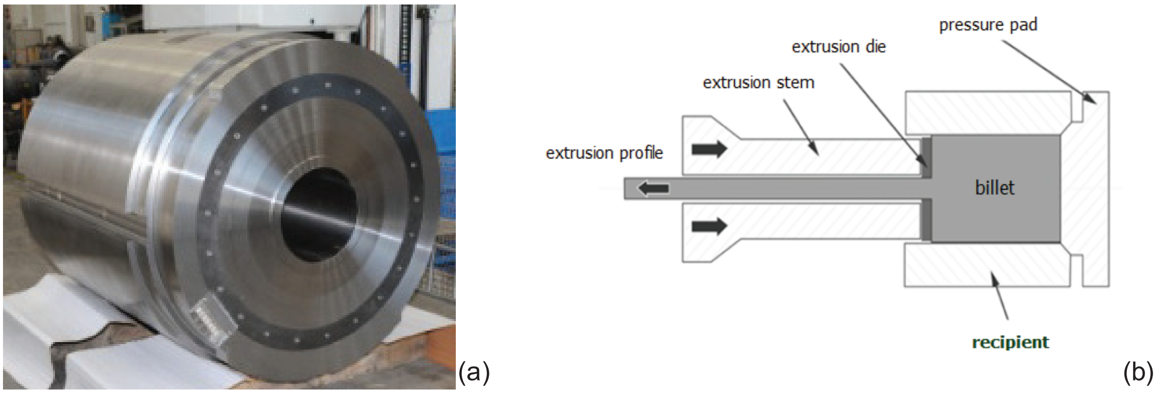

Figure 2: (a) Extrusion recipient and (b) indirect extrusion process [24-27]

4.2 Flow Structure Modelling

For modelling material flows, Umberto® applies the following elements [28]:

- *Transitions*, symbolised by squares, represent processes which transform materials or energy and, thus, also quantity centres corresponding with these processes. If a more detailed analysis of a transition is desired, a subnet for this transition can be created. This is indicated by a subnet transition in Umberto®.
- *Places,* symbolised by circles, have different functions. Firstly, they can represent *inputs* or *outputs of the considered system* and, thus, system boundaries. Secondly, they can also stand for *storages* of materials (or energy). Thirdly, they serve as *connections* between transitions. All these types of places become so-called *port places* if they neighbour subnet transitions.
- *Arrows* connect transitions with places and specify the flow direction.

Flow structure modelling in Umberto® (resulting in a so-called material flow network) begins with the specification of *system boundaries* (step 3 of the PDCA-Cycle, figure 1) which is modelled by the definition of input and output places bounding the network [28]. Afterwards, the *time period* has to be fixed. Umberto® provides a standard period of one year, but, the user can define other time periods, reaching from one day up to several years. In the example of recipient manufacturing, the system boundaries are defined by the places of providing the raw material (P1-P3) and the finished recipient (P20) as well as different waste outputs (P27-P33) (figure 3). It is assumed that the time period spans one year and thereby comprises the typical manufacturing cycle of approximately three to four months.

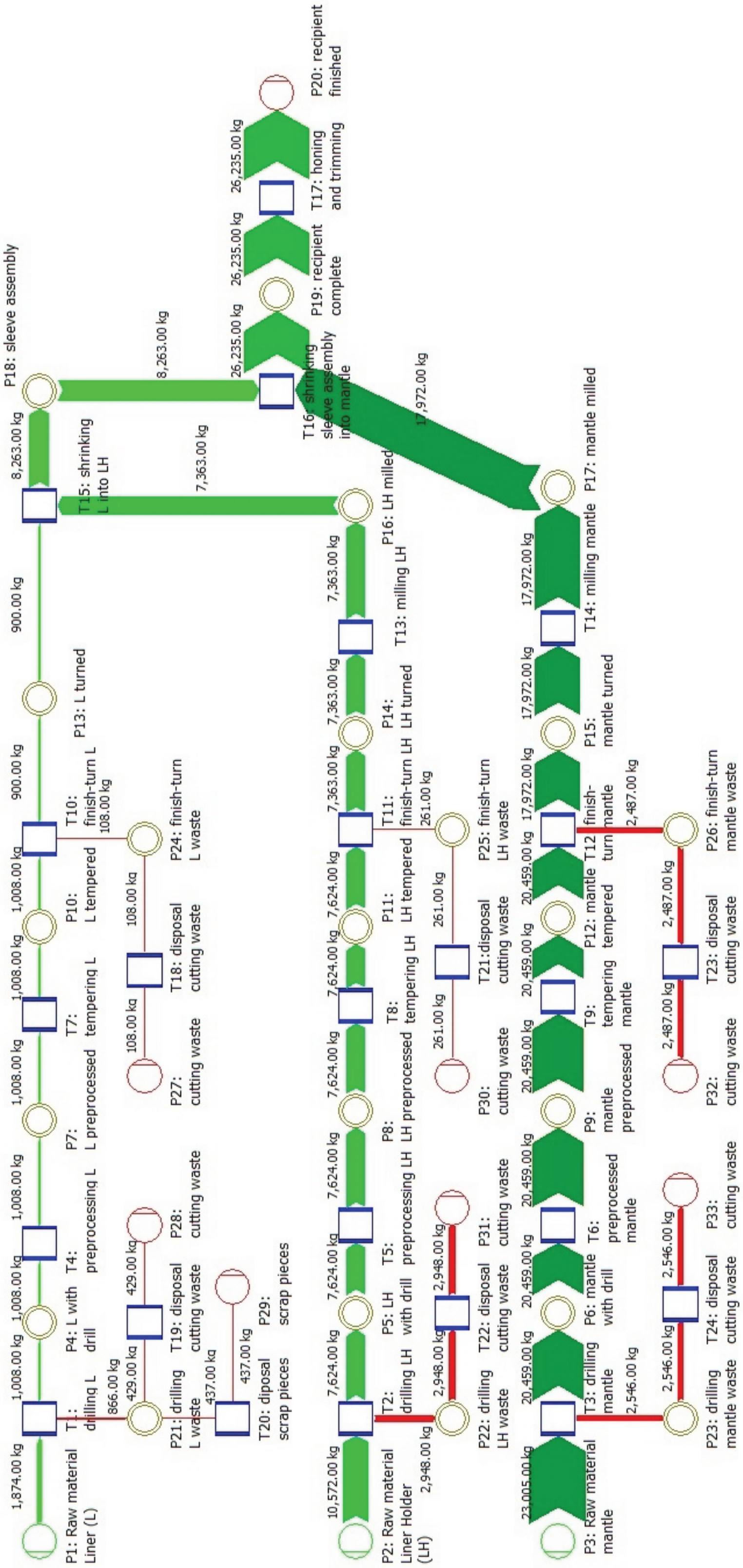

Figure 3: Sankey diagram of the material flow network of recipient manufacturing (kg)

For the determination of quantity centres (step 4) in Umberto®, a transition has to be inserted for each quantity centre representing a step of recipient manufacturing (T1-T17, figure 3). Furthermore, the processes of dealing with different waste categories (which cause waste management costs but also generate revenues) are also modelled by transitions (T18-T24). Storages as another possible type of quantity centres according to DIN EN ISO 14051: 2011 are not explicitly considered here. In Umberto®, they rather would have been represented by places.

For the *identification of inputs and outputs for each quantity centre* (step 5), a list of materials (e. g. raw materials, energy (defined as “material” in Umberto®), semi-finished products, final products and waste/emissions) has to be created and material types have to be defined. Umberto® distinguishes between three material types: good, bad and neutral. Flows of good (bad) materials are symbolised by green (red) arrows, neutral materials (being irrelevant for the production system, e. g. oxygen in the atmosphere [28]) are neglected here. Based on the material list, each material can be assigned to a quantity centre (transition) – as an input or output (or both).

The flow structure can be modelled with different levels of detail. To reach a high level, processes are decomposed in sub-processes or activities. In Umberto®, sub-nets representing these sub-processes or activities may be defined by using subnet transitions and port places.

4.3 Quantification of Material Flows

For the *quantification of* inputs and outputs of quantity centres and, thus, the *material flows in physical units* (step 6), in Umberto® different options exist: So-called basic units are "kg" and "kJ" by default, besides, other physical units (e. g. pieces, gram or cubic metres) can be represented by self-defined basic units or “display units” (representing input or output data). Using these types of units, for each quantity centre (transition) input/output relations have to be specified either with coefficients or by non-linear functions. Thus, it is possible to take economies of scale into account. Additionally, the inputs and/or desired outputs of the material flow system have to be entered. By linking inputs/outputs with coefficients/functions, the flow structure model is enhanced to a quantity flow model comprising the quantities of flows [6, 33]. In Umberto®, these quantities of flows can be assigned to the arrows and/or symbolised by the width of the arrows (see figure 3). In line with this, for each transition, section or subnet in the material flow network or even the entire network, material balances ("Balance Sheets") can be displayed [28].

Figure 4 shows the quantified input and output of the whole material flow network of recipient manufacturing. Raw materials as input of recipient components’ manufacturing are on the input side. The finished recipient as well as different waste categories are displayed on the output side.

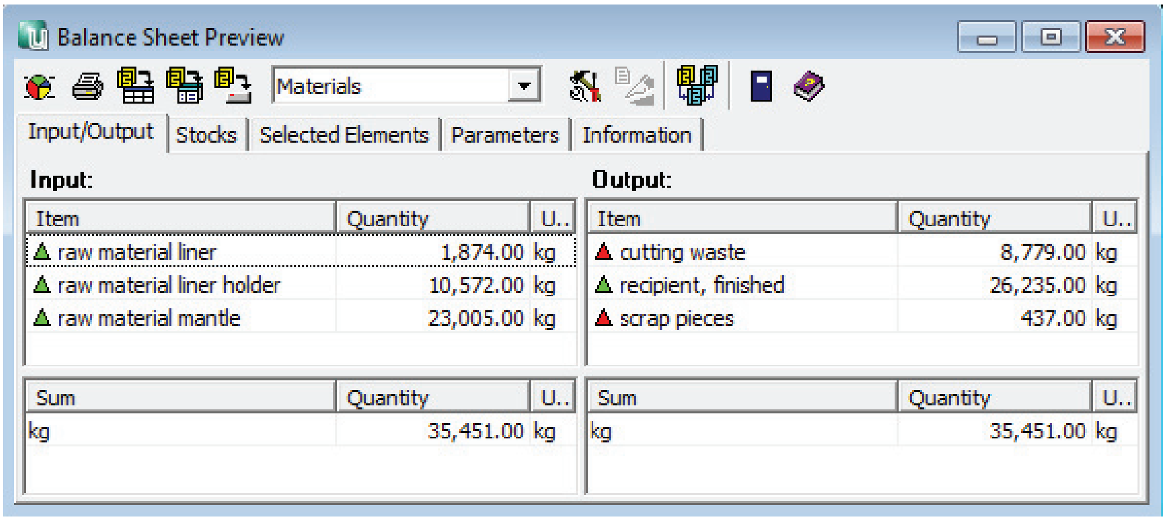

Figure 4: Exemplary Balance Sheet Preview for the material flow network of recipient manufacturing

4.4 Evaluation of Material Flows

Based on the previous steps, the *quantification of the material flows in monetary units* (step 7 of the PDCA-Cycle according to DIN EN ISO 14051: 2011, figure 1) can be realised. In other words, a flow cost model is created and analysed [30, 31]. Therefore, Umberto® provides a cost accounting tool which supports Full Cost Accounting as well as Variable Cost Accounting (Direct Costing). In contrast, DIN EN ISO 14051: 2011 does not differ between fixed and variable costs and, thus, implicitly refers to Full Cost Accounting. The following explanation also refers to Full Cost Accounting.

To accomplish the creation and analysis of the flow cost model, a procedure with seven steps is proposed [28]:

- Establishing a cost plan that defines all material-flow relevant cost type groups (e. g. material costs, energy costs, system costs), cost types and cost drivers. Cost drivers are used to calculate and allocate all costs except of material costs. For each transition several cost drivers can be defined. Thus, a differentiated analysis especially of the heterogeneous system costs (consisting of e. g. labour costs, depreciation and other costs for equipment [5]) is possible.
- Specifying the standard market price of relevant materials.
- Determining the (non-material) costs of the various quantity centres (in Umberto® named as cost centres at this point) on the base of the previously defined cost drivers.
- Selecting or defining rules or coefficients (representing the share of costs of a specific type which are caused by a specific flow) for the allocation of quantity centre costs to material flows. Predefined rules comprise the allocation of

costs according to material quantities, costs and numerical values of material properties. Thereby, Umberto® provides the opportunity for a differentiated cost allocation, based on several criteria. Thus, waste management costs, for example, can be allocated solely to waste while other cost centre costs are distributed to products as well as waste.

- Calculating the total costs of single quantity centres (transitions) as well as the material flows of a subnet or the entire flow system. Therefore, cost rates are multiplied with the corresponding quantities (cost rates (standard market prices) for material with quantities of material flows, or, costs per cost driver unit (e. g. machine hours) with the corresponding number of units). Thereby, basic units have to be considered. If the basic unit is "kg" for example, a relationship between "kg" and the value of other cost drivers (e. g. “hour”) has to be defined.
- Selecting a reference flow whose costs shall be displayed.
- Editing the data to display them in a so-called balance sheet.

The previous description shows that Umberto® can be used to support step 7 of the PDCA-cycle, the quantification of the material flows in monetary units. Besides, it provides a basis for the steps 8 and 9, *MFCA data summary and interpretation* and *communication of MFCA results*. For reporting of MFCA results, Umberto® facilitates the display of Sankey diagrams (with quantity or cost flows), material and cost balances and ratio systems. However, Material Flow Cost Matrices [4, 18] cannot be visualised.

Typical results of the usage of Umberto® are displayed in a Sankey diagram using the example of recipient manufacturing (figure 5). Here, the width of the arrows symbolises the amount of (dummy) costs. The (in Umberto® red coloured) arrows connecting T1-P28/P29, T2-P31, T3-P33, T10-P27, T11-P30 and T12-P32 represent the costs of material losses as one significant result of MFCA. The comparison of figure 3 and figure 5 shows differences between the relative quantities and costs of product and loss flows. For example, the incoming and the outgoing arrow in T5 have the same width in figure 3, based on the assumption that there are no quantity differences. In figure 5, the outgoing arrow is wider than the incoming arrow because of added system costs. As a second example, it can be seen that cutting waste in P28 is less cost-intensive than cutting waste in P27. The relation of quantities in figure 3 is nearly 4:1 while the relation of costs in figure 5 is approximately 2.5:1. This can be explained by the increasing value of materials within material flows.

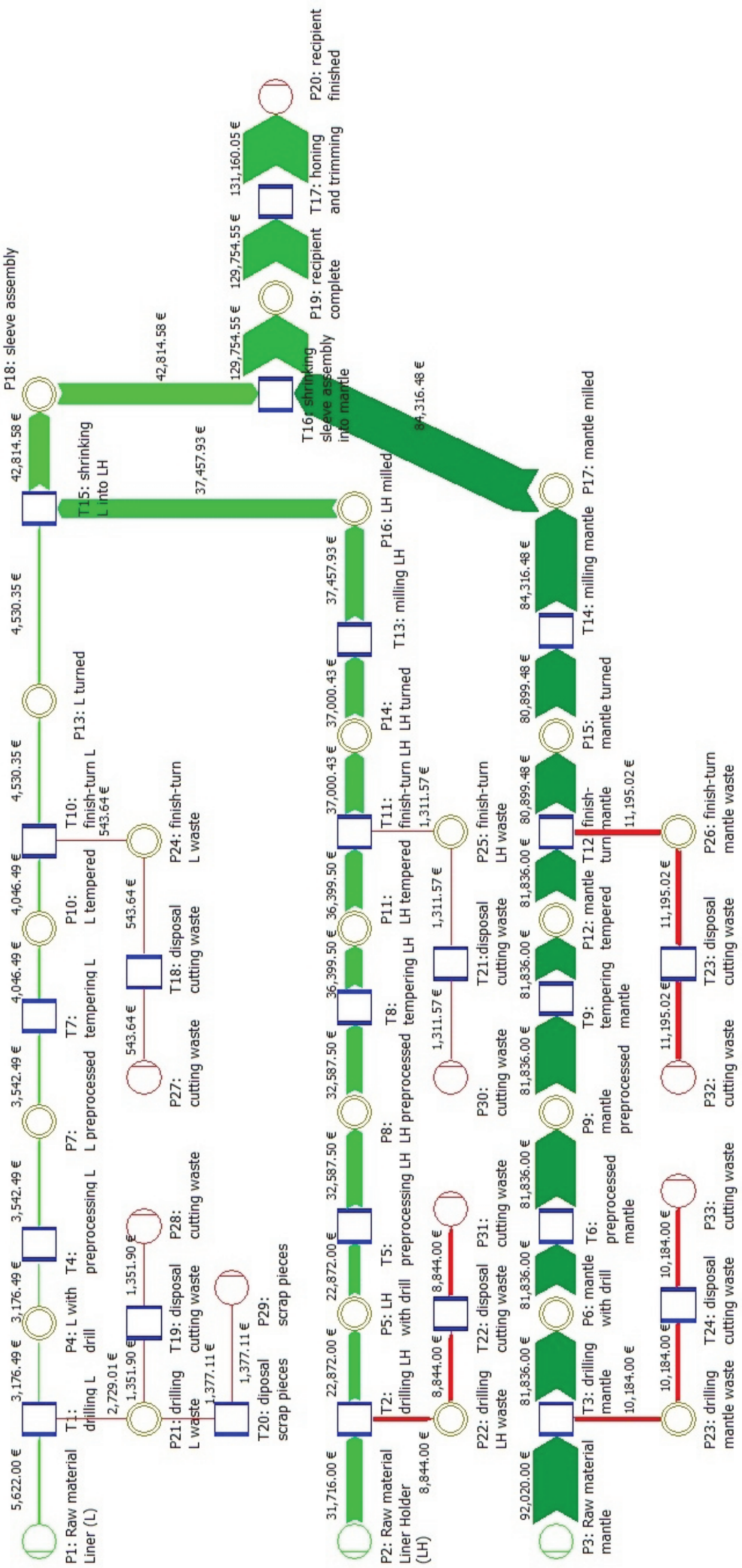

Figure 5: Sankey diagram for the material flow network of recipient manufacturing (Euro)

Additionally, in a “Balance Sheet” the costs can be displayed differentiated according to cost types (figure 6). Thus, the composition of costs is revealed. Figure 6 refers to the whole flow system. However, separate balances for product or waste flows or specific subnets can be created, too. For example, cost unit based product balances (Life Cycle Inventories (LCI’s)) enable the separate display of variable and fixed costs. Despite of the wording in figure 6, it does not necessarily refer to variable (proportional) costs – in Umberto® one and the same template is used for Variable Cost Accounting as well as Full Cost Accounting.

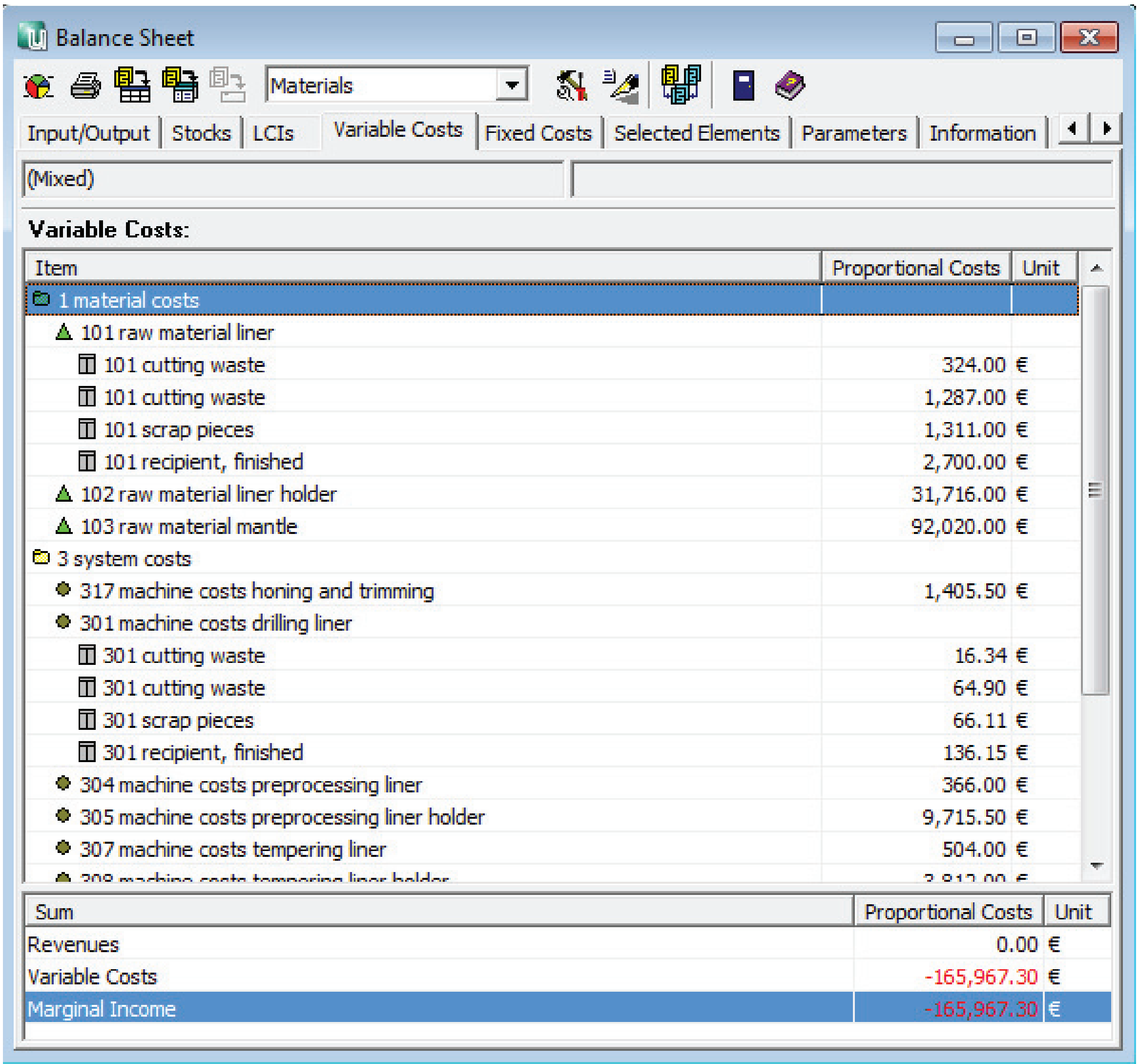

Figure 6: Balance Sheet of (dummy) costs of recipient manufacturing

5 Potentials and possible refinements

To summarise, Umberto® proves to be useful for the flow structure modelling, quantification of material flows, modelling and analysis of cost flows and presentation of the overall results of Material Flow Cost Accounting. Furthermore, it has the potential for integrating Life Cycle Assessment and MFCA and, thus, ecological and economic evaluations on the base of specific material flow networks. However, some aspects of the modelling procedure might be discussed and possibly refined:

- On the one hand, it is possible to classify material as “good” or “bad”. On the other hand, a bad output cannot be a cost unit (cost carrier) in Umberto®. To enable the calculation of the costs of material losses – as a core result of Material Flow Cost Accounting – all input and output materials, even waste, have to be typed as “good”. In general, the terminology is partly different from those of MFCA (according to DIN EN ISO 14051: 2011) causing the necessity of “translation”. As a second example, the heterogeneous representation of quantity centres (manufacturing processes etc. by transitions, storages by places) shall be mentioned here.
- Energy is seen as material in spite of its (often) non-material character. For energy-intensive production systems, a refinement might be helpful.
- To what extent can the differentiation between variable and fixed costs contribute to the support of decision making regarding material (and energy) consumption? In DIN EN ISO 14051 this differentiation is not elaborated [4].
- Cost appraisal does not acknowledge time value of money as it is adequate for long-term decision making – costs from different periods cannot be discounted by the tool (for Discounted Cash Flow Methods see [32]).
- Finally, it would be interesting how Umberto® can be integrated with the various existing (traditional) cost accounting systems and IT tools. For example, the divergence between cost centres and quantity centres has to be handled.

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