Target costing for energy- and cost-oriented product development

Bierer, A.[1]; Götze, U.[1]

[1] Chemnitz University of Technology, chair of management accounting and control

Abstract

Mechanical engineering companies are facing the challenge to develop and manufacture cost efficient *and* energy efficient machine tools. While numerous means and methods for the development of cost or of energy efficient machines exist, there is a lack in methodological support for a development process considering both targets. To fill this gap, the paper presents adaptations of target costing for energy- and cost-oriented controlling of design specifications. Selected results are demonstrated and discussed by a case study from mechanical engineering.

Keywords:

target costing, energy efficiency, machine tool design

1 Introduction

With ecodesign strategies, mechanical engineering companies want to reduce negative environmental impacts of the machine tools' use and manufacturing (e. g., minimizing toxic chemicals releases), optimize raw material consumption and energy use, reduce (life cycle) cost, and meet "user needs/wants by exceeding current expectations for price, performance and quality" [1]. In particular, energy-related sub strategies are an important field. These so called design to energy efficiency (DtEE) strategies aim at ensuring that machine tools meet customer needs for energy efficient products [2, 3] and/or at improving the energy efficiency of the manufacturers' production processes [4]. On the one hand, the relevance arises from the fact that machine tools in their use phase and the processes to manufacture them take energy inputs to transform material inputs into products and wastes and therefore predominantly influence the industrial environmental outcome and energy con-

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sumption. On the other hand, efforts for improving energy efficiency will have positive and negative effects on the machine’s (life cycle) cost and will thus influence a company’s earnings in different ways. Therefore, a DtEE strategy requires paying attention to both energy conservation measures and the effects of reducing energy consumption on various types of cost. So, the need for methodological support for the development of energy *and* cost efficient products is evident.

Against this background and based on conventional target costing (section 2), the paper suggests three adaptation paths for the controlling of product development processes by energy and cost targets (section 3). One of these paths is described and discussed in a case study (section 4). The paper closes with summary and conclusion (section 5).

2 Target costing-basics

Target costing is a "cost management tool for reducing the overall cost of a product over its entire life cycle with the help of the production, engineering, R&D, marketing, and accounting departments" ([5], S. 41). It can be used for effective market- and cost-oriented controlling of design specifications and production techniques over the entire product life cycle. The basic procedure is shown in Figure 1.

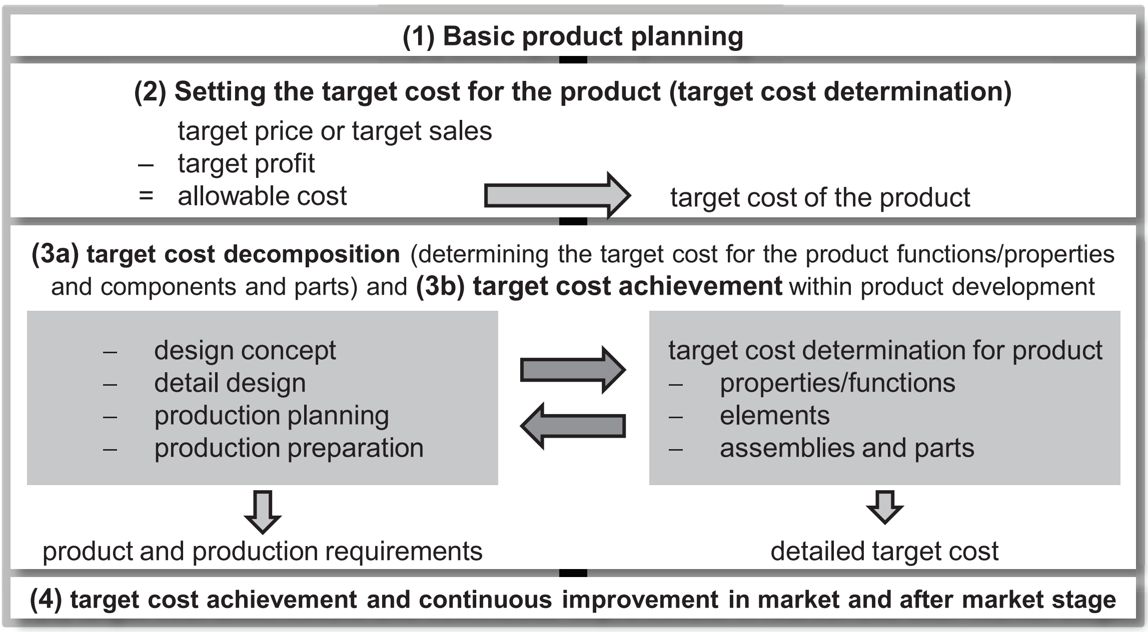

Figure 1: Target Costing Procedure (following [6])

The procedure starts with basic product planning. The preparation of a basic product plan takes the company’s product and business strategy, market trends and the needs of potential customers into account. On the one hand, this plan includes the positioning of the product in the market. On the other hand, it contains the main product properties required by the customers.

Target cost determination usually begins with establishing a market-oriented target price. Then, the target cost is computed by subtracting a target profit margin from that price. Please note that the starting point is not necessarily a target price. Instead, a current cost level of similar products (out of standard cost) or competitive products (out of competitor) can be used as well. Then, the target cost is calculated by subtracting required cost savings from the current or competitor cost level.

In the next step, the target cost is decomposed using previously defined criteria and decomposition paths (e. g., from customer requirements over product functions and components to single parts). In target achievement, methods for cost-driven development and product modifications are applied. To control the design specifications with respect to the customer requirements and the cost target, a target cost index is calculated as basis for comparisons between planned/targeted cost and actual achievable cost. The step is completed when the product meets the requirements and the costs are within the given target cost limit.

The last step leaves the basic concept somehow. It aims at the not exceeding the follow-up cost of a product`s life cycle [7]. Accordingly, efforts are directed to maintenance activities and continuous improvement throughout the whole product life cycle to aspire that the target life cycle cost is always kept.

3 Energy aspects in target costing

As already mentioned, with a DtEE-strategy the development engineers must balance the potentially conflicting energy- and cost-related goals. In order to support DtEE, a target costing instrument must be able to control the design specifications with respect to energy efficiency and/or cost (from energy cost up to life cycle cost). Basically, different scenarios combining various dimensions, in particular, the company's perspective, the considered life cycle phases and the types of targets, can be created.

The most important dimension is "types of targets". The literature discusses various cost items to be used as targets, i. a., production costs, costs of R&D, operations and maintenance costs, recycling costs, life cycle cost, ecological costs, environmental life cycle cost, or the net present value on the basis of discounted cash flows. These are all monetary targets. But with respect to the aim of target costing for DtEE, to plan and control energy efficient design specifications also non-monetary targets like energy consumption, conservation and/or emission reduction should be applied.

This corresponds with the fact that the scope of the monetary and non-monetary targets can range over the whole life cycle of a machine tool, from the initiation of a development project over manufacturing and usage, up to recycling and disposal.

Beyond that, it can be distinguished between the company's perspectives when applying target costing. With respect to DtEE, a manufacturer as well as a supplier aims at achieving i. a., its own energy-related manufacturing costs or energy conservation in the production process and/or the user's energy-related costs or energy consumption of a machine tool during its operation and maintenance phase. If a company does not manufacture all product elements by itself, it acts as a customer for the element suppliers and may apply target costing to identify target prices for purchase assemblies or parts, but also to determine their energy-related requirements (minimum energy consumption, maximum energy efficiency, etc.).

In conclusion, the described aspects can be variably combined to pursue different energy-related design goals in product development. With respect to the most important dimension, the targets, three development paths for integrating energy-related aspects into target costing have been identified (Figure 2). Please note that these paths can be combined with various company's perspectives and life cycle phases. For example, a manufacturer may use target energy management to develop a machine tool with low energy consumption during operation and maintenance.

Except for target energy management, the approaches work with cost- as well as energy-related targets. That means it must be regarded that targets could have complementary effects (e. g., a reduction of energy consumption in the use phase reduces the energy cost in the use phase), conflicting effects (e. g., the reduction of energy consumption in the use phase may cause higher manufacturing cost) or no mutual influence.

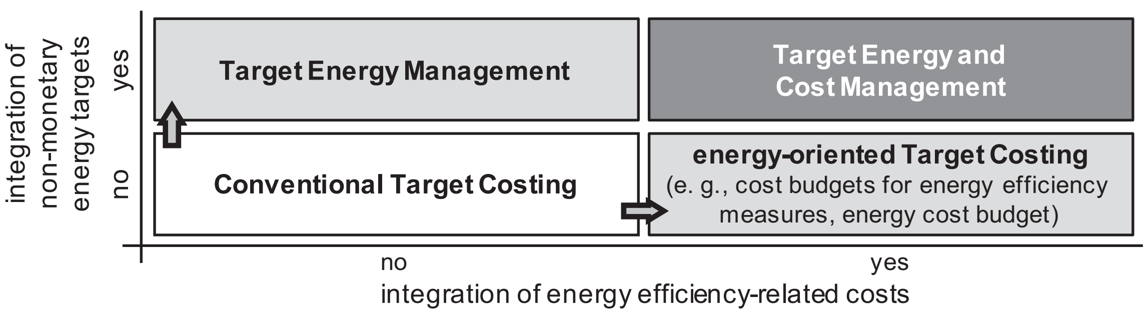

Figure 2: Dimensions and development paths of target energy and cost management

In the following, the three development paths are outlined with their basic concepts and assumptions.

Energy-oriented target costing

This approach is directed to a manufacturer's aims to develop energy-efficient products and to manufacture them in an energy-efficient way at a competitive cost level. The approach comprises all energy-related methodological adaptations and enhancements of conventional target costing where cost efficiency is the only target. It is assumed that energy efficiency (or equivalent targets) can be a product or a manufacturing process property that should be fulfilled together with other requirements as best as possible with respect to a set cost target.

As a product property, energy efficiency is required by the market or a certain customer. It indicates that the product to be developed should be more energy efficient in its use phase. In order to control this property explicitly, a target cost budget for the realization of measures for product's energy efficiency improvement should be defined and allocated to energy-relevant product elements.

As a requirement of the product's manufacturing process, energy cost can be used instead of energy efficiency or energy consumption in production. They can be integrated by setting energy cost budgets for the elements' manufacturing processes. Taking the conventional procedure, the overall target cost are estimated and allocated to the machine tool functions on the basis of their respective benefit for requirements fulfillment. Then, the target cost is decomposed to the elements and subdivided into cost budgets for the different types of the producer's manufacturing costs, in particular for energy costs, but also for material costs, direct labor costs, purchased parts costs, etc. [8]. This enables the development engineers to select manufacturing technologies and configure manufacturing process chains wherewith a given energy cost budget can be achieved.

Target Energy Management

Energy-oriented target costing aims at developing energy-efficient machine tools at a competitive cost level. But, what to do when the focus is on energy consumption, e. g., a product is required to have a certain energy consumption or a consumption that will be lower than that of already manufactured or competitive products? To plan and control the development and manufacturing of a product consuming "less energy", neither its manufacturing or life cycle cost nor any other monetary target, especially the energy costs the product causes during its use, would be exclusively appropriate types of targets. This is due to the fact that design decisions which are directed towards energy conservation affect different cost types in different ways. In many cases, the manufacturing of products consuming less energy in its operation phase cause higher manufacturing cost than comparable ones. Therefore, costs seem to be not good indicators for the development of low energy products. To face this specialty, a target energy management approach is suggested, using non-monetary targets but measurable and controllable target variables like energy consumption, energy conservation or carbon emissions instead of cost targets.

Target Energy and Cost Management

The previously presented approaches can only provide selective support. In energy-oriented target costing, the energy-related cost budgets could limit the feasibility of measures or strategies to improve the energy efficiency. In target energy management, highly energy efficient products are developed, but their (perhaps disproportionately high) manufacturing or life cycle costs remain unknown. Because of this, the integrated approach of target energy and cost management is suggested. It aims at the concurrent energy- and cost-related controlling of design specifications in the development process. For it, target values are determined or derived for both the cost target and a non-monetary energy target. Using the market-driven function-oriented decomposition method, the targets are allocated to product functions and elements. With the help of means and measures for cost and energy savings in product development and the after-development stages of the product life cycle, a global energy and cost efficiency optimum should be achieved.

4 Target Energy and Cost Management – A case study

4.1 Case study introduction

In this section, the application of integrated target energy and cost management (TECM) is presented and discussed using the simplified example of a mechanical engineering company developing an energy and cost efficient turning and milling center (short TMC) for a specific customer (customer/market into company strategy). Further, it is assumed that

- cost and energy consumption should be proportional to the customer benefit,
- the company applies the function-oriented decomposition method.

For estimating the TMC cost, the company does not only want to rely on engineering standards. Instead, it wants to establish the target cost and target energy consumption derived from customer demands and with respect to market benchmarks. So, following conventional target costing, the procedure is based on the assumption that the cost and energy consumption rates should be proportional to the customer benefit. This means the higher a customer rates the benefit of a certain machine tool function or element the higher are the allowed cost and energy consumption shares for this function or element.

Applying the function-oriented method, the target allocation will start with identifying and weighting the main machine tool functions. Then, the targets are further allocated to the machine tool elements and the elements' target values are computed.

The TECM procedure follows the general target costing steps (section 2): It starts with basic product planning including the identification and weighting of the customer requirements. Then, the cost- and energy-related targets are determined and decomposed to the TMC functions and TMC elements on the basis of their particular contribution to property fulfillment. In an iterative process of synthesis, analysis, and verification steps both targets should be achieved as best as possible under the constraint of fulfilling all customer requirements.

4.2 Basic product planning and target determination

Basic product planning

Since usually machine tools are not developed from scratch, there already exist relatively detailed and comprehensive plans of machine tools or machine tool elements. So, the basic product plan is derived from existing machine tools and the product specification sheet. After consulting the customer, besides various technical properties, two mandatory requirements have been derived: The TMC must have a maximum tolerable price (p) of 950,000 € and should need 25 % less energy than a comparable machine tool. Beyond that, the customer has the following demands (required properties ($r = 1, \ldots, R$)) and assigns them following weights (property weighting ($w^{(R)}_r$)) (Table 1).

Table 1: Required properties and their weights

required properties	weighting
low processing time	21.000%
high product quality	21.000%
quick tool change/low secondary time	16.000%
recycables and waste handling	16.000%
integrated quality control	11.500%
low maintenance requirements	3.000%
complete machining by flexible process combination	3.000%
high product and volume flexibility	3.000%
ease of use	3.000%
little space requirement	2.500%
	100.000%

Target determination

For target determination, the mechanical engineering company pursues the market into company-strategy. The targets are determined on the basis of the customer requirements. Since the manufacturer wants to realize a profit with the TMC, he subtracts a profit margin (pm) of 5 % from the maximum tolerable price (p) to get the overall target manufacturing cost (C^T) for the TMC.

$$C^T = p - p \cdot pm = 902{,}500\,€ \tag{1}$$

For the energy conservation requirement, the company identified the most similar machine tool with respect to the other required properties. This TMC has an averaged standard energy consumption (EC^S) of about 132.5 kW. This value should be reduced by 25 %. The resulting target energy consumption (EC^T) is set to 100 kW.

4.3 Target decomposition

In this next step, the target manufacturing cost (C^T) and target energy consumption (EC^T) are allocated. The function-oriented decomposition method (see [9, 10]) is used for both targets. First, the targets are allocated to main machine functions (following the functional structure in [11]) and then to main machine elements (following common literature, e. g., [12]).

The process of target decomposition starts with determining the contribution ($w^{(F)}_{fr}$) of each TMC function ($f = 1, \ldots, F$) to required properties fulfillment. The determination of the contributions is based on estimations by domain experts.

Table 2: Contribution of the main machine functions to required properties fulfillment

required properties / main machine functions	low processing time	high product quality	quick tool change	recycables and waste handling	integrated quality control	low maintenance requirements	complete machining …	high product/ volume flexibility	ease of use	little space requirement
$w^{(R)}_r$ →	0,2100	0,2100	0,1600	0,1600	0,1150	0,0300	0,0300	0,0300	0,0300	0,0250
machining	0,6000	0,6000	0,3500	0,0000	0,8000	0,2500	0,7000	0,4000	0,4000	0,2500
process conditioning a. cooling	0,2000	0,1000				0,4000	0,1000	0,0500		0,2000
tool handling/tie handling		0,0500	0,6000		0,2000	0,0500	0,1000	0,3000	0,2500	0,1500
workpiece handling		0,0500	0,0500			0,0500	0,1000	0,2500	0,2500	0,0500
recycables a. waste handling	0,0500	0,0500		0,9000		0,2000				0,1500
machine cooling a. heating	0,1500	0,1500				0,0500				0,0500
security				0,1000					0,1000	0,1500
	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000

Based on these estimations, it is possible to compute "benefit ratios" for the functions ($n^{(F)}_f$) by summarizing the products of the functions contribution to properties fulfillment ($w^{(F)}_{fr}$) and the properties weights ($w^{(R)}_r$):

$$n_f^{(F)} = \sum_{r=1}^{R} w_{fr}^{(F)} \cdot w_r^{(R)} ; \forall f = 1,\ldots,F \quad (3)$$

The benefit ratio of a function represents its total contribution to requirements fulfillment. The results are listed in Table 3.

Table 3: Benefit ratios for the TMC functions

required properties / main machine functions	low processing time	high product quality	quick tool change	recyclables and waste handling	integrated quality control	low maintenance requirements	complete machining …	high product/ volume flexibility	ease of use	little space requirement	function benefit ratios ($n^{(F)}_f$)
machining	0.1260	0.1260	0.0560	0.0000	0.0920	0.0075	0.0210	0.0120	0.0120	0.0063	0.4588
process conditioning a. cooling	0.0420	0.0210	0.0000	0.0000	0.0000	0.0120	0.0030	0.0015	0.0000	0.0050	0.0845
tool handling/tie handling	0.0000	0.0105	0.0960	0.0000	0.0230	0.0015	0.0030	0.0090	0.0075	0.0038	0.1543
workpiece handling	0.0000	0.0105	0.0080	0.0000	0.0000	0.0015	0.0030	0.0075	0.0075	0.0013	0.0393
recycables a. waste handling	0.0105	0.0105	0.0000	0.1440	0.0000	0.0060	0.0000	0.0000	0.0000	0.0038	0.1748
machine cooling a. heating	0.0315	0.0315	0.0000	0.0000	0.0000	0.0015	0.0000	0.0000	0.0000	0.0013	0.0658
safety	0.0000	0.0000	0.0000	0.0160	0.0000	0.0000	0.0000	0.0000	0.0030	0.0038	0.0228
	0.2100	0.2100	0.1600	0.1600	0.1150	0.0300	0.0300	0.0300	0.0300	0.0250	1.0000

If needed, the sub-targets for the functions can be calculated by multiplying the overall targets with the benefit ratios. Since it is similar to the target determination for the elements it is not included here.

On a second decomposition level, the contributions ($w^{(E)}_{ef}$) of the main machine elements (*e = 1, …, E*) to the realization of the main machine functions are also estimated by domain experts (Table 4).

Table 4: Contributions of the machine elements to function fulfillment

main machine functions / main machine elements	machining	process conditioning and cooling	tool handling	workpiece handling	recycables and waste handling	machine cooling and heating	security
($n^{(F)}_f$) →	0.4588	0.0845	0.1543	0.0393	0.1748	0.0658	0.0228
machine fundament	0.0200						
chassis (beds, standards, tables)	0.0500		0.0500	0.0300			
guidance elements	0.1000		0.0500	0.0200			
main spindle assembly	0.3500	0.2500	0.1000	0.2000			
auxiliary drive assemblies	0.2000	0.2500	0.1000	0.2000	0.1000	0.1500	
tool/die holder	0.0500	0.2000	0.2500				
tool changer	0.0500		0.3000				
workpiece holder	0.0500			0.3000			
control and operating element					0.0500	0.1000	0.5500
supply and disposal elements	0.0300	0.2500			0.6500	0.6500	
compressed air system (incl. machine cooling)	0.0500		0.1000	0.2500			
hydraulic system	0.0500		0.0500		0.0500		
machine housing and cover panel		0.0500			0.1500	0.1000	0.4500
	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

On the basis of these results, benefit ratios ($n^{(E)}_e$) can be determined for every machine element.

$$n_e^{(E)} = \sum_{f=1}^{F} w_{ef}^{(E)} \cdot n_f^{(F)} ; \forall e = 1,\ldots,E \qquad (6)$$

The benefit ratio of a machine element represents its total contribution to required properties fulfillment (Table 5).

Table 5: Benefit ratios for the machine elements

main machine functions / main machine elements	machining	process conditioning and cooling	tool handling	work-piece handling	recyclables and waste handling	machine cooling and heating	security	element benefit ratios ($n^{(E)}_e$)
machine fundament	0.0092	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0092
chassis (beds, standards, tables)	0.0229	0.0000	0.0077	0.0012	0.0000	0.0000	0.0000	0.0318
guidance elements	0.0459	0.0000	0.0077	0.0008	0.0000	0.0000	0.0000	0.0544
main spindle assembly	0.1606	0.0211	0.0154	0.0079	0.0000	0.0000	0.0000	0.2050
auxiliary drive assemblies	0.0918	0.0211	0.0154	0.0079	0.0175	0.0099	0.0000	0.1635
tool/die holder	0.0229	0.0169	0.0386	0.0000	0.0000	0.0000	0.0000	0.0784
tool changer	0.0229	0.0000	0.0463	0.0000	0.0000	0.0000	0.0000	0.0692
workpiece holder	0.0229	0.0000	0.0000	0.0118	0.0000	0.0000	0.0000	0.0347
control and operating element	0.0000	0.0000	0.0000	0.0000	0.0087	0.0066	0.0125	0.0278
supply and disposal elements	0.0138	0.0211	0.0000	0.0000	0.1136	0.0427	0.0000	0.1912
compressed air system (incl. machine cooling)	0.0229	0.0000	0.0154	0.0098	0.0000	0.0000	0.0000	0.0482
hydraulic system	0.0229	0.0000	0.0077	0.0000	0.0087	0.0000	0.0000	0.0394
machine housing and cover panel	0.0000	0.0042	0.0000	0.0000	0.0262	0.0066	0.0102	0.0473
	0.4588	0.0845	0.1543	0.0393	0.1748	0.0658	0.0228	

With help of this preliminary work, the target manufacturing cost and the target energy consumption of the machine elements can be determined. Starting with the cost target, an element's manufacturing cost can be calculated by:

$$C_e^T = n_e^{(E)} \cdot C^T \quad (7)$$

Together with the standard element cost ($C^S{}_e$), the resulting target element cost ($C^T{}_e$) is listed in the Table 6. For every element, the absolute need for cost reduction (ΔC) and a target cost index (*TCI*) are computed. The target cost index represents a benefit ratio ($n^{(E)}{}_e$) to cost share ($c^S{}_e$) measure. With respect to the proportionality assumption (see section 4.1), an machine element with a *TCI > 1* (*TCI < 1*) could be interpreted as being overengineered (too simple), because its standard cost share is higher (lower) than the benefit share a customer would assign to it.

Table 6: Target cost-related results

	$n^{(E)}_e$	C^T_e	C^s_e	ΔC	c^s_e	TCI
machine fundament	0.0092	8,280.44	5,750.00	-2,530.44	0.0058	1.60
chassis (beds, standards, tables)	0.0318	28,724.32	26,345.00	-2,379.32	0.0263	1.21
guidance elements	0.0544	49,071.18	83,245.00	34,173.82	0.0832	0.65
main spindle assembly	0.2050	184,978.66	150,333.00	-34,645.66	0.1503	1.36
auxiliary drive assemblies	0.1635	147,547.47	154,916.00	7,368.53	0.1549	1.06
tool/die holder	0.0784	70,756.00	77,464.00	6,708.00	0.0775	1.01
tool changer	0.0692	62,464.28	48,695.00	-13,769.28	0.0487	1.42
workpiece holder	0.0347	31,328.03	42,445.00	11,116.97	0.0424	0.82
control and operating element	0.0278	25,112.06	15,467.00	-9,645.06	0.0155	1.80
supply and disposal elements	0.1912	172,569.28	265,003.00	92,433.72	0.2650	0.72
compressed air system (incl. machine cooling)	0.0482	43,477.94	43,220.00	-257.94	0.0432	1.11
hydraulic system	0.0394	35,547.22	41,439.00	5,891.78	0.0414	0.95
machine housing and cover panel	0.0473	42,643.13	45,678.00	3,034.88	0.0457	1.03
	1.0000	902,500.00	1,000,000.00	97,500.00	1.0000	

Analog to the cost-related results, a machine element's target energy consumption (EC^T_e) can be computed by:

$$EC_e^T = n_e^{(E)} \cdot EC^T \qquad (8)$$

The results, including the energy consumption values of a comparable machine's elements (EC^S_e) and saving potentials (ΔEC^S_e) are presented in Table 7.

Table 7: Target energy consumption-related results

	$n^{(E)}_e$	EC^T_e	EC^s_e	ΔEC	ec^s_e
machine fundament	0.0092	0.918	0.00	-0.92	0.0000
chassis (beds, standards, tables)	0.0318	3.183	0.00	-3.18	0.0000
guidance elements	0.0544	5.437	2.00	-3.44	0.0151
main spindle assembly	0.2050	20.496	45.17	24.67	0.3409
auxiliary drive assemblies	0.1635	16.349	38.03	21.68	0.2870
tool/die holder	0.0784	7.840	0.00	-7.84	0.0000
tool changer	0.0692	6.921	1.53	-5.39	0.0115
workpiece holder	0.0347	3.471	0.00	-3.47	0.0000
control and operating element	0.0278	2.783	1.67	-1.11	0.0126
supply and disposal elements	0.1912	19.121	25.70	6.58	0.1940
compressed air system (incl. machine cooling)	0.0482	4.818	11.30	6.48	0.0853
hydraulic system	0.0394	3.939	7.10	3.16	0.0536
machine housing and cover panel	0.0473	4.725	0.00	-4.73	0.0000
	1.0000	100.00	132.50	32.50	1.0000

A potentially computed target energy consumption index (*TECI*) can be expressed by the proportion of the benefit ratio ($n^{(E)}_e$) to the energy consumption share (ec^S_e). Figuratively, the *TECI* could be interpreted similar to the *TCI*.

4.4 Target achievement

The properties required by the customer and the results of target decomposition provide the basis for the directed development of the TMC. In an iterative process of synthesis, analysis, and verification steps (see i. a. [13]) the development engineers apply strategies and methods for cost and energy reduction in order to achieve the set targets. In the synthesis step, energy and/or cost saving solutions are searched or new solutions developed for the identified needs of action. In particular, for energy efficiency improvement strategies and energy conservation of machine tools, respectively, see i. a. [14] and [15]. Then, feasibilities and prospects of found possible solutions are analyzed and evaluated. Having transformed the selected measures into design specifications, the resulting concept or draft is verified. During verification, methods of measurement, estimation, calculation and/or simulation are applied to forecast the cost and energy consumption achievable with the current design specification. These values are compared to the target values to evaluate the degree of target achievement. The target achievement process in product development is finished, when all required properties are fulfilled and the target manufacturing cost and the TMC's energy consumption are within the set limits.

Target achievement process should not stop after the TMC is developed, manufactured and sold to the customer. Usually, a machine tool has an expected useful life of about 8 to 15 years. In this time, the machine should be operated within the specified admissible machine parameters (e. g., capacity limit, maximum cutting speed, component weights) and periodically serviced and preventively maintained to keep the cost and the energy consumption low or even reduce them.

4.5 Discussion

In particular, together with target energy and cost management as described above four basic aspects should be discussed:

a) missing prioritization of the two targets,

b) target decomposition based on the commonly used element benefit ratios,

c) cost and energy consumption are proportional to the customer benefit,

d) type of target representing the energy consumption or efficiency target.

The first point refers to the aspect that the manufacturer is confronted with different types of target relations (see section 3). However, the respective saving potentials are calculated separately. But up to now, potentially existing complementarities or conflicts between the two targets have not been considered. For example, a target conflict could cause the problem that the development engineers do not know if they could realize energy saving measures despite they would exceed the respective element's target cost, and vice versa. In principle, there are different options to deal with these conflicting targets. Two self-evident alternatives could be: assigning priorities to the targets or choosing especially improvement measures with complementary effects on both targets.

As already stated at the beginning of section 4, the described target energy and cost management is based on two general target costing assumptions: the target decomposition bases on the customer benefit (second point) and it is assumed that the elements' cost and energy consumption are proportional to the elements' contribution to requirement fulfillment (third point). These assumptions generally affect the significance and feasibility of target costing results. In target energy and cost management, they cause a specific problem: As section 4.3 shows, the TMC functions, elements and their interrelations are identified independent of the targets by domain experts and/or on the basis of existing machine tool breakdowns. In the case study, energy saving requirements are assigned to energy consuming assemblies like the main spindle or the auxiliary drive components, but also to not energy consuming components like machine fundament or chassis components (see Table 7). A possible solution may be the exclusion of all non-energy consuming elements with a reallocation of the benefit ratios to the remaining energy-using elements (Table 8).

Table 8: Reviewed target energy consumption-related results

	$n^{(3')}_e$	EC^T_e	EC^s_e	ΔEC	ec^s_e
machine installation and fundament	0,0000	0,000	0,00	0,00	0,0000
chassis (beds, standards, tables)	0,0000	0,000	0,00	0,00	0,0000
guidance elements	0,0795	7,954	2,00	-5,95	0,0151
main spindle assembly	0,2301	23,013	45,17	22,16	0,3409
auxiliary drive assemblies	0,1887	18,866	38,03	19,16	0,2870
tool/die holder	0,0000	0,000	0,00	0,00	0,0000
tool changer	0,0944	9,438	1,53	-7,91	0,0115
workpiece holder	0,0000	0,000	0,00	0,00	0,0000
control and operating element	0,0530	5,300	1,67	-3,63	0,0126
supply and disposal elements	0,2164	21,638	25,70	4,06	0,1940
compressed air system (incl. machine cooling)	0,0733	7,335	11,30	3,97	0,0853
hydraulic system	0,0646	6,456	7,10	0,64	0,0536
machine housing and cover panel	0,0000	0,000	0,00	0,00	0,0000
	1,0000	100,00	132,50	32,50	1,0000

Even though this allocation is also no optimum at all, it supports a more realistic assignment. Further options for energy-related target allocation (also for other non-monetary targets) may be

- the use of different target specific product structures (e. g., bill of material, energy-oriented or manufacturing parts list) as basis for target decomposition;
- a preliminary decomposition of the energy consumption target into sub targets for operating states (e. g., standby, ready for operation, processing) similar to the customer requirement distinction in the Kano model [16, 17];
- the principle application of different determination and decomposition strategies (e.g., market into company, out of company) and methods (e. g., benefit-oriented component- or energy consumer-related allocation, domain expert-

based assignment of energy or cost saving potentials to energy consuming assemblies, subassemblies and parts).

These and – when indicated – further options and approaches, respectively, should be elaborated and discussed with respect to their feasibility for energy-related or other non-monetary targets.

Finally, the case study uses a power value as energy-related target. However, a power consumption value is often employed, since an energy consumption value requires substantial and extensive measurements and/or calculations. But the use of power values seems to be discussable. The energy consumption of a machine tool and therewith the required power input fluctuate depending on the type and function of the machine element and the machine's operating state. Accordingly, further research is needed to identify more qualified energy-related target variables and to align them with appropriate energy-related determination and decomposition strategies and methods.

5 Summary and conclusion

The paper presented adaptations of target costing for energy-sensitive target (cost) management. Using a machine tool case study, basics and a possible procedure of target energy and cost management have been demonstrated. Afterwards, the process and the results have been discussed with respect to open questions.

As sections 3 and 4.5 indicate, different paths of an integration of energy aspects into target costing have been identified. First means and methods for their concrete design have been outlined. But further research must be done to specify them, especially with respect to non monetary targets.

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