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ON ENGINEERING MEANINGS AND REPRESENTATIONS OF TECHNICAL FUNCTIONS

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ABSTRACT

In this paper I consider the relations between the different meanings and representations of the concept of technical function that are in use in engineering design methodology. I focus on two representation schemes – the verb-noun and the operation-on-flows representations – and analyse whether representations of technical functions created with the one scheme can be transposed into representations of the same functions with the other scheme. I argue that the answer depends on the particular meaning of function that one adopts. When functions of technical systems refer to behaviours of those systems, then the two representations can be reciprocally transposed following the rule that the verbs in the verb-noun representations correspond to the operations in the operation-on-flows representations, and the nouns to the (main) flows. When, however, technical functions refer to the purposes for which systems are designed, it can be argued that these representations cannot be transposed using this rule. The reason for this result is that operation-on-flows combinations, where the flows are flows through technical systems, are, in general, not suited to represent purposive technical functions of the systems. In a subsidiary and more explorative discussion I focus on the transposition of verb-noun representations of purposive functions into operation-on-flows representations of behavioural functions in design methodologies such as the Functional Basis account of Robert Stone and Kristin Wood.

1. INTRODUCTION

Technical functions pose a paradoxical challenge to any conceptual analysis of engineering. It is by now common knowledge that in engineering design methodology authors give different meanings to this concept [1-5] and that they represent functions in various ways [4,6,7]. Authors may take functions as purposes (e.g., [8,9]), as intended parts of behaviour (e.g., [10,11]) or as behaviour that contributes to satisfying needs (e.g., [12]), and authors may switch between options [8,13,14] or adopt two meanings simultaneously (e.g., [4,15]). Authors may represent functions by verb-noun pairs (e.g., [3,12,16]), using operations on physical flows (e.g., [12,16]), transformations of states (e.g., [17]) and using combinations thereof (many examples). Facing this multiformity, the time seems right to analyses the situation and determine which meanings and representations can be unified, or at least integrated, into one general understanding. The benefits of such a project are also acknowledged in the literature: technical function is a key-concept in a broad spectrum of engineering activities, and all these activities would gain considerably from a generally shared understanding of technical functions by, for example, enabling unambiguous exchange and storage of functional information in natural and formalised computer languages. Yet, the challenge is not just one of disambiguating an important concept. It consists also of breaking the current *status quo*. The lack of a common general understanding of technical functions is, as said, noted in the literature but not systematically taken to be problematic: developments in engineering seem not to have suffered from the coexistence of different meanings and representations for the concept of function, and this seems to have established acceptance that this concept does not need a single understanding. Individual authors typically do provide single analyses of technical functions, but these analyses are taken as additional possibilities rather than as rejections of existing analysis: and in attempts that have been made towards the formalisation of engineering language, the decision may be made to relate all possible meanings rather than to adopt any one at the expense of the others (e.g., [5], §7, [18]). This *status quo* turns the burden of proof onto those who still feel the need to disambiguate the concept of function. When taking up the challenge of arriving at a unifying account, one simultaneously has to establish the worth of the project and point out to engineers what they will gain with a unified or integrated understanding of technical functions.

In this paper I will not attempt to unify or integrate the different engineering uses of the concept of technical functions, nor to prove that engineering will gain from analyses of the current labyrinth of engineering meanings and representations. The question that I address here is one about the interrelatedness of these different meanings and representations. Are these representations independent of the particular meanings of the concept of function? Or does adopting a particular meaning rule out the use of particular representations? More specifically I consider two representation schemes – verb-noun and operation-on-flows representations – and analyse whether representations of technical functions created with the one scheme can be transposed into representations of the same functions in the other scheme. I argue that the answer depends on the particular meaning of function that one adopts, thus establishing that functions that are understood as purposes are, in general, not representable by operations on flows in a straightforward manner.

As said, I will not prove that this result improves engineering by, for instance, presenting empirical data about how designing, manufacturing or production becomes more efficient when the engineers concerned have a better understanding of the relations between the different meanings and representations of technical functions. The result has a bearing on design methodology, which I will discuss. More generally I motivate this work by the position that a field in science and technology is improved by a better understanding of its conceptual framework. Finally, the current labyrinth of meanings and representations of functions is simple too interesting to leave it as it is; it begs us to engineering an overall understanding.

In Sections 2 and 3 I introduce the two representations I focus on. Then, in Section 4, I consider how operation-on-flows representations of technical functions are transposed into verb-noun representations in design methodology, focussing in particular on the use of these two representations in the methodology of Robert Stone and Kristin Wood [12]. In Section 5 I take up the reverse question of how verb-noun representations of functions are transposed into operation-on-flows representations, and argue that this transposition is not feasible when functions of technical devices are understood as their purposes. Yet, verb-noun representations of purposive functions are in design methodologies assumed to be transposable into operation-on-flows representations. In Section 6 I explore means by which this transposition can still be achieved.

2. VERB-NOUN REPRESENTATIONS

Technical functions of technical systems seem generally to be representable using pairs of verbs and nouns. Natural language descriptions of technical functions are typically phrased in verbs, and also commonly in nouns: and if they are only phrased in verbs, it is often possible to add the noun in an unambiguous way. The function of a pump, for instance, may be described as to *pump*, and this description can be quickly completed to give to *pump fluid*.

Verb-noun representations can be taken as semi-formalised and standardised natural language descriptions of technical functions. According to some authors verbs and nouns can be chosen freely, as when the verb-noun pairs represent overall functions of technical systems [12]. Other authors take the choice to be regimented by rules and/or hierarchical word lists. Jacobson *et al*., for instance, require that the verb is a transitive verb and give a hierarchical classification of allowed verbs and nouns [19]; Sturges *et al.*, require that the verbs are active verbs, i.e., to *support load* instead of *providing support* [20]; and Miles advises us to employ verb-noun pairs with measurable parameters for use functions, i.e., to *support weight* instead of to *support component x* [21]. Regimentation is found especially when the represented functions are basis functions. Authors generally assume that a set of functions exists in technology that are basic in the sense that all other technical functions can be analyses as combinations of the functions in the set. There are a number of proposals for fixing these basis functions, most of which are given as glossaries of the verbs and nouns used to represent them (e.g., [16,22]; see also Tables 1 and 2 in Section 4).

One critical point that may be raised against taking verb-noun representations as generally applicable is that in some cases verb-noun descriptions seem to be too limited. If, for instance, a function concerns a transformation, then a sufficiently informative description in terms of verbs and nouns should include at least two nouns, as in to *transform electrical energy into rotational energy*. In many of the examples given by authors that employ these representations, these more complicated descriptions are included (e.g., [20], figs. 9A-E and 12, [12], figs. 6 and 7; see also Fig. 3 in Section 4 of this paper).

3. OPERATION-ON-FLOWS REPRESENTATIONS

Technical functions of technical systems also seem to be generally representable using operations that technical systems perform on physical flows through such systems. Technical systems are all designed to interact with us and with their environments, and by the laws of physics these interactions can be understood in terms of flows of physical systems that are exchanged between the technical systems and their environments, including us. Physical systems that enter technical systems define input flows, and physical systems that leave technical systems define output flows. This entering and leaving of technical systems is defined more precisely by introducing *system boundaries* for technical systems that are crossed by the input and output flows [12,16], or by introducing (spatial) *control volumes* around technical systems [9]. A function of a technical system can now be represented using these input and output flows and the operation the technical system performs on the input flows to obtain the output flows. If technical functions of systems are taken as the intended behaviour of such systems, then, for instance, the functions can be represented by the operations that transform the intended parts of the input flows into the intended parts of the output flows. Note: operations on flows can also be used to represent the *behaviour* of technical systems; however, specifying the full input and output flows may involve long lists; focussing only on the intended parts of behaviour allows us to avoid this problem when representing technical functions.

The characterisations of operations and flows are also typically regimented. A widespread approach is to sort the flows in the categories of *materials*, *energies* and *signals* [3,12,16]. Furthermore, the input and output flows are often assumed to be obeying the relevant conservation laws [12], a requirement which is sometimes made quite explicitly [9]. Finally, for basis functions, the flows and operations are limited to those found in the glossaries that list the basis functions (e.g., [16,22,23]).

Proponents of the approach in which the flows are sorted as material, energy and signal flows, have already noted one disadvantage of their approach: these flows are not independent. Material flows and signal flows are always accompanied by their associated energy flows [16], which suggest grouping these associated flows [24] thus arriving at flows that correspond to, physically, more realistic flows [25]. A second disadvantage that can be noted is that physical categories that do not straightforwardly count as materials, energy or signals, still have to be accommodated. Force, for instance, which can be taken as input and output for structural elements in technical systems – e.g., pillars in bridges – is taken as a special case of energy [22]. Alternative approaches to this first approach are available. In [9], for instance, the main flow categories are mass, energy and information, but also momentum, force, charge, and electromagnetic waves.

It can, thirdly, be doubted whether the input and output flows in operation-on-flows representations should obey conservation laws. Consider, for instance, a battery sealed in a throwaway camera, or a sound baffle. These systems have the technical functions to generate electrical energy when a photograph is taken, and to reduce the intensity of sound waves. An operation-on-flows representation of the function of the battery could be to *transform an input force* (a push on the camera's switch) *into an electrical energy*, and the representation of the function of the sound baffle could be to *reduce the intensity of the input sound waves with fifty percent*. Yet, in these two cases the input and output flows clearly do not satisfy the laws of energy conservation. Conservation laws seem rather to apply to representations of the physical behaviour of systems; when one is describing the behaviour of the battery or sound baffle that make that these systems can perform their functions, then it is relevant to add that the chemical energy in the battery decreases and that the baffle produces warmth when reducing the intensity of sound waves. In the Multilevel Flow Modelling approach of Morten Lind [23] this conservation-laws requirement is not adopted. In this approach a distinction is made between the flows of materials and energy, and those of information and (human) actions. The basis operations defined for material and energy flows now include *source* and *sink*, which are clearly ones that violate conservation laws by allowing output flows without input flows and *vice versa*.

4. A TRANSPOSITION RULE

As said in the introduction, engineers often use the different available representations of technical functions simultaneously. In the design methodology of Gerhard Pahl and Wolfgang Beitz [16] and in the Functional Basis account of Robert Stone and Kristin Wood [12], for instance, the operation-on-flows and the verb-noun representations exist side-by-side, and designers are assumed by these authors to be able to transpose them easily. To illustrate this, and to have a case for discussing the transpositions of the two representations, I briefly present Stone and Wood's description of conceptual designing.

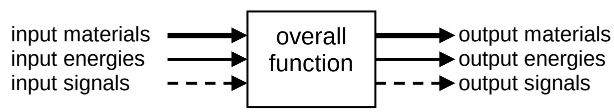

Figure 1. Representation of an overall product function or of a subfunction, following [12].

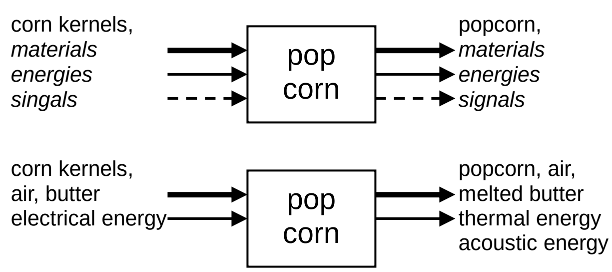

Figure 2. Initial and final representation of the overall product function of a popcorn popper, following [12].

The first task for a designer, when determining the functional structure of a new technical system is, according to Stone and Wood ([12], §5), to arrive at a black box model of the overall product function described in both the verb-noun form (Stone and Wood speak about a verb-*object* form) and a black-boxed operation on flows of materials, energies and signals (see Fig. 1). This black box model originates from customer needs and is initially typically quite general and coarse grained, but later on, when the determination of the functional structure progresses, the model of the overall product function is refined to include the input and output flows necessary to realise the black-boxed operation of the initially identified material, energy and signal flows. Thus, in terms of Stone and Wood's example of a hot air popcorn popper (see Fig. 2, adapted from [12], fig. 7), the overall product function is initially described as to *pop corn*, with an input material flow of corn kernels, an output material flow of popcorn, and the rest of the flows left unspecified. Later in the design process these remaining flows are specified, the input consists of flows of corn kernels, butter, air and electrical energy; the output of popcorn, melted butter, air, thermal energy and acoustic energy. The designer is able to come up with this refinement by analysing the initial black-boxed overall product function in terms of subfunctions, which defines the next task in conceptual designing.

This second task is to define for each input flow, a chain of subfunctions that transforms that flow step-by-step into, parts of, the output flow. These subfunctions are also described in verb-noun forms and represented by operations on flows, but now the verbs must be chosen from a fixed library of basis operations, and the flows from a fixed library of basis flows. The two libraries make up the functional basis and are listed in Tables 1 and 2, respectively (they are the improved libraries given in [22] and the third level of tertiary functions and flows is not included). The subfunctions part of the different chains must be ordered in time with respect to one another.

Table 1. Library of basis operations; [22].

primary functions	secondary functions
branch	separate
	distribute
channel	import
	export
	transfer
	guide
connect	couple
	mix
control magnitude	actuate
	regulate
	change
	stop
convert	convert
provision	store
	supply
signal	sense
	indicate
	process
support	stabilize
	secure
	position

The third task is to integrate these temporally ordered chains of subfunctions by connecting the chains, thus arriving at the decomposition of the overall product function. The energy flow part of the popcorn popper's functional decomposition is given in Fig. 3 (taken from [12], fig. 7, with terminology adjusted to the libraries of [22]). The energy arrows at the right-hand side pointing to the right are output flows, the energy arrows at the bottom pointing downwards and upwards are internal flows to and from the other chains of subfunctions. The designer thus has to analyse the initially identified input flows of the overall function in terms of flows from the library of basis flows, and then produce a series of operations from the library of basis operations that sequentially and/or in parallel transforms this input step-by-step into basis flows that, together, make up the initially identified output flows. Using this procedure all kinds of additional input and output flows can be recognized as needed to indeed transform the initially identified input into the initially identified output. Thus, when transforming corn kernels into popcorn, flows of air and energy, etc., are also needed, and once added, this gives us a final, more detailed, representation of the overall product function (see again Fig. 2).

Table 2. Library of basis flows; [22].

primary flows	secondary flows
material	human
	gas
	liquid
	solid
	plasma
	mixture
signal	status
	control
energy	human
	acoustic
	biological
	chemical
	electrical
	electromagnetic
	hydraulic
	magnetic
	mechanical
	pneumatic
	radioactive/nuclear
	thermal

The basis subfunctions that decompose the overall product function are assumed by Stone and Wood to be functions that have easy design solutions in terms of existing components. The design process thus proceeds by collecting the relevant components and aggregating them to obtain a first structural design of the technical system. For the topic of this paper, the details of this aggregation [12,26] are less relevant.

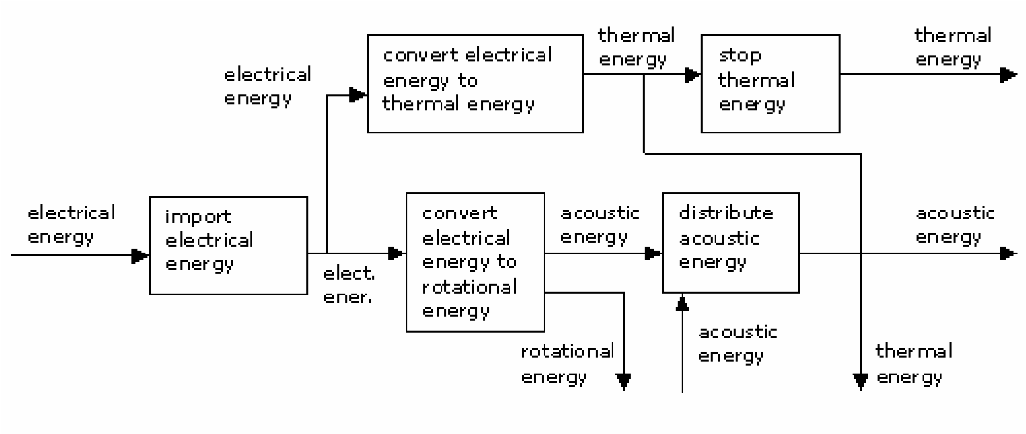

Figure 3. Part of a functional decomposition of to pop corn; [12], fig. 7.

The verb-noun representations of the overall product functions and of the basis subfunctions and their operation-on-flows representations are in the Functional Basis approach related by the following rule: the verbs correspond to the operations, and the nouns correspond to the main parts of the input and output flows. For instance, the overall product function of the popcorn popper is to *pop corn* such that the initial input and output flows consist of *corn*, and the operation is one of to *pop*. This rule for transposing the two types of representations seems straightforward and is also adopted by other authors. Jakobson et al. ([19], page 222) for instance, stated that "the verb [..] indicates the operation and the noun the object or operand". Yet, it can be shown that this rule cannot hold in general.

5. BEHAVIOURAL AND PURPOSIVE FUNCTIONS

Verb-noun representations of functions can, in many cases, be reciprocally transposed to operation-on-flows representations using the rule that the verbs correspond to the operations, and the nouns to the main parts of the input and output flows. The transpositions of the verb-noun and operation-on-flows representations of the function of the popcorn popper, illustrate successful use of this rule. Yet, other examples of verb-noun representations of functions create less attractive results, primarily because it is assumed that the flows in the operation-on-flows representations are flows that go *through* the systems with the functions concerned. Consider the technical function to *cool human body* of an electric fan (this example is adopted from [27]) and the function to *detect planes* of radar [28]. Application of the mentioned rule shows that the functions are represented by the operation to *cool* on an input-output flow consisting of a *human body*, and the operation to *detect position* on a flow of *planes*. Yet, human bodies do not enter or leave electric fans, and neither do planes go through radar installations. The proper way of representing the functions of fans and radar using operations on flows is by, say, to *convert electrical energy to a flow of air* for the fan and to *convert electrical energy to signals that reveal plane positions* for radar. Hence, for some functions the relationship between their verb-noun and operation-on-flows representations is more complex that assumed: the verbs do not need to correspond to the operations and nor do the nouns need to correspond to the (main) flows.

This problem has two sides. One is the conceptual riddle that a combination of three acceptable assumptions leads to a conclusion that is not so acceptable. These assumptions are that (*i*) functions of technical systems can be represented by verb-noun pairs, that (*ii*) functions of technical systems can be represented by operation-on-flows combinations, where the flows go through the systems, and that (*iii*) the relation between the two representations is that the verbs correspond to the operations and the nouns to the (main) flows. The riddle can be solved by denying or qualifying at least one of these assumptions. Yet this solution does not immediately solve the second side of the problem, which is the design-methodological issue of coming up with an alternative relation between verb-noun and operation-on-flows characterisations of technical functions. Return, for instance, to Stone and Wood's description of the tasks of which conceptual designing consists. Customer needs with respect to the technical system to be designed, can still be characterised by verb-noun pairs such as to *cool human body* and to *detect planes*. Thus, to carry out the first task the designer still needs rules to transpose these characterisations into black-boxed operation-on-flows descriptions, where the flows go through the product; without these rules the designer would, for instance, not be able to start with the second task of analysing the black-boxed operation-on-flows descriptions in terms of the basis operations given in Table 1. In this section I focus on the conceptual side, in the next section I explore ways to address the second design-methodological issue.

To solve the conceptual riddle, one can start with noting that assumptions (*i*) and (*ii*) are both ambiguous in their references to functions. As said in the introduction, authors take different positions about what this concept means, and if this disagreement is explicitly taken into account, it can be argued that operation-on-flows combinations can represent behavioural functions but not, in general, purposive functions.

The first position is that functions of technical systems are physical behaviours of those systems for which it holds that the behaviours contribute to satisfying the customer needs. This seems to be the position Stone and Wood take, given the requirement that the flows in the operation-on-flows representations of functions should obey conservation laws: this requirement makes sense when one wants to represent behaviours. With this position, the assumptions (*i*) and (*ii*) are tenable: behaviours of technical systems can reasonably be represented by verb-noun pairs and operation-on-flows combinations. Assumption (*iii*) also seems to give a tenable relation between these two representations; the riddle is solved by noting that the counterexample verb-noun pairs to *cool human body* and to *detect planes* do not refer to particular behaviours of a fan or radar installation, and thus cannot count as functions of these technical systems. The descriptions to *cool human body* and to *detect planes* may refer to customer needs or to purposes of fans and radar, but these needs or purposes need not be representable using operations-on-flows, where the flows go through fans or radar.

The second position is that functions of technical systems are such parts of the physical behaviours of those systems that are intended by users or designers. In this position the flows in the operation-on-flows representations of functions need not obey conservation laws since users and sometimes even designers, may not be interested in that aspect of behaviour. Lind [23] may be taken as holding this position since in his position the creation of energy and matter may be a function; and when functions are represented by pairs of triggers and effects, e.g., operating a switch (trigger) for letting the light go on (effect), one also holds this position [11], because trigger-effect pairs describe the intended input and output flows only and may clearly violate conservation laws. Note: the initial black-boxed description of the overall product functions in Stone and Wood's methodology (see the previous section and Fig. 2) may also be taken as intended-parts-of-the-behaviour functions; yet, some of the subfunctions Stone and Wood include in their analyses of the overall product functions need not count as intended functions: the subfunction to *distribute acoustic energy* (see Fig. 3) may be a behaviour of the popcorn popper nobody is interested in although it has to be included in the analysis to let the functional decomposition meet the relevant conservation laws [28]. In this second position, the assumptions (*i*) and (*ii*) are tenable: the intended parts of the behaviours of technical systems can reasonably be represented by verb-noun pairs and operation-on-flows combinations. Assumption (*iii*) also seems to give a tenable relation; the problem is again solved in the fan and radar cases by noting that the verb-noun pairs to *cool human body* and to *detect planes* do not refer to particular behaviours of the fan or radar, and thus cannot count as functions of these technical systems.

The final position is that functions of technical systems are the purposes for which the systems are designed. These purposes may still be behaviours or parts of behaviours, but no longer need to be behaviours that are strictly interpretable as behaviours of the technical systems. These *purposive* functions are said to be at a higher abstraction level than the (abstraction) level of the behaviour of technical systems by Chakrabarthi [15], or are analysed as intended behaviour of technical systems *plus* their environments by Chandrasekaran and Josephson [10]. In this position, assumption (*i*) is still tenable: behaviours of technical systems plus their environments can reasonably be represented by verb-noun pairs. Yet, the second assumption (*ii*) ceases, in general, to be tenable: the explicit possibility that the function concerns behaviour of a system different to the technical system, makes that functions are not in general to be understood as operations on flows, where the flows go through the technical system. The problem is now solved by noting that the counterexample verb-noun pairs to *cool human body* and to *detect planes* represent purposive functions that cannot be represented using operations-on-flows, where the flows go through the systems.

Thus, the conceptual riddle is solved when it is realised that the concept of function can be understood in different ways. When understanding functions of technical systems as behaviours of these systems, all three assumptions are tenable: for the two types of behavioural functions discussed in this section it holds that (*i*) behavioural functions of technical systems can be represented by verb-noun pairs, (*ii*) behavioural functions of technical systems can be represented by operation-on-flows combinations, where the flows go through the systems, and (*iii*) the relation between the two representations is that the verbs correspond to the operations and the nouns to the (main) flows. The counterexamples to *cool human body* and to *detect planes* are, in this case, to be taken as invalid since they cannot be taken as particular behaviours of fans or of radar and hence not as behavioural functions. When understanding functions of technical systems as their purposes, assumption (*ii*) becomes untenable, and assumption (*iii*) consequently meaningless: (*i*) purposive functions of technical systems can be represented by verb-noun pairs, but it is not always the case that (*ii*) purposive functions of technical systems can be represented by operation-on-flows combinations, where the flows go through the systems.

A response to the last conclusion may be that application of the rule captured by assumption (*iii*) to verb-noun representations of purposive functions such as to *cool human body* and to *detect planes* yields perfectly acceptable results: the fan has the purposive function of applying the operation of *cooling* to a human body, and radar has the purposive function of applying the operation of *detecting* to planes. Yet, the flows involved, that of the human body and that of planes, can only be taken as flows through the fan or through radar if the system boundaries or control volumes of these systems (see Section 3) are enlarged to include the areas in which these flows are located. For radar one can argue that such an enlargement is reasonable; especially if a radar installation consists of a number of ground stations it is practice to understand 'radar' as the area scanned, and to say that planes fly through radar. For fans the expansion is *ad hoc*, and even with this expansion, the operation-on-flows representations are representations of the functions of fans and radar as understood in the enlarged area sense. This little digression leads us to the additional conclusion that, after all, purposive functions can be represented as operations on flows: the result is merely that purposive functions of technical systems cannot be represented as operations on flows, when such flows go *through* the systems. So, for purposive functions, the conclusion remains that verb-noun and operation-on-flows representations cannot be transposed with the rule that the verbs correspond to the operations, and the nouns correspond to the main parts of the input and output flows; the nouns in the verb-noun representations and the (main) flows in the operation-on-flows representations need not coincide because the latter always go through the technical system having the purposive function, whereas the former need not.

6. FROM VERB-NOUN REPRESENTATIONS OF PURPOSIVE FUNCTIONS TO OPERATION-ON-FLOWS-REPRESENTATIONS OF BEHAVIOURAL FUNCTIONS

With the conceptual side of the problem of relating verb-noun and operation-on-flows representations out of the way, the design-methodological side of this problem remains: What are the rules for transposing verb-noun representations of, in particular, purposive functions into (black-boxed) operations-on-flows representations of behaviour-type functions, where the flows go through the product? This transposition is part of the first task of conceptual designing, as identified by Stone and Wood [12].

In this section I consider two ways in which this transposition can be carried out. One specific way is relatively simple and is derived from the functional-decomposition analysis of behavioural functions of technical systems in terms of behavioural functions of their components. This analysis can be generalised to a procedure to analyse purposive functions of technical systems in terms of behavioural functions of those systems. A second more general possibility is more intricate and involves introducing in the transposition the ways in which technical systems are used. This second possibility consists of identifying purposive functions and behavioural functions of technical systems using *environment-centric* and *device-centric* functions, respectively, as defined by Chandrasekaran and Josephson [10]. The discussion presented here of these two possibilities is explorative: I hope to sketch ways in which the design-methodological issue of relating verb-noun and operation-on-flows representations can be addressed; other and better possibilities may be available, and my sketches can certainly be improved.

The first possibility uses the fact that verb-noun representations of purposive functions of technical systems can be transposed into operation-on-flows representations of the functions, where the flows go through the *environment* of the technical system. The design-methodological issue then becomes one of how an operation on flows through a large system consisting of the technical system plus its environment, can be analysed in terms of operations on flows through only the smaller technical system. The procedure of functional decomposition described by Stone and Wood (see Section 4) seems suited to address this issue. Stone and Wood use it to analyse operations on flows through the technical system as a whole, i.e., a large system, in terms of operations on flows through components, i.e., smaller systems. If this procedure can be generalised, it may also give us the means to transpose operation-on-flows representations of purposive functions of technical systems into operation-on-flows representations of behavioural functions of such systems. Consider again the electric fan and the radar installation. Their purposive functions to *cool human body* and to *detect planes* may be represented by the operations-on-flows *separate thermal energy from human body* and *detect position of planes*, where the 'flows' of a human body and of planes are flows through the environments of the fan and the radar, respectively. These environmental operations-on-flows may now be analysed in terms of operations-on-flows within the fan and the radar, i.e., operations-on-flows that can be taken as representing behavioural functions of the fan or radar. This analysis may be taken as the (spatially) *scaling down* of the operations-on-flows by reducing the system boundaries from the environments of technical systems to the technical systems (the relation between the distinction between purposive and behavioural functions and the drawing of system boundaries is also noted in [15]). In the case of the electric fan the operation-on-flows *separate thermal energy from human body* is then analysed to consist of *convert electrical energy to a flow of air*, and a number of other operations-on-flows, such as, *transfer flow of air* (from fan to human body), *connect flow of air and human body* and *transfer thermal energy from human body to flow of air*. The operation-on-flows *convert electrical energy to a flow of air* is one localised within the fan, and one that can be taken as representing its behavioural function; the other operations-on-flows take place outside the fan, and may be taken as taking place automatically. In the case of radar the operation-on-flows *detect position of planes* may in turn be analysed as consisting of, say, *converting electrical energy into electromagnetic energy*, *dissipate electromagnetic energy*, *scatter electromagnetic energy at planes*, *detect electromagnetic energy*, *indicate location and time-delay of the electromagnetic energy*. Some of these operations-on-flows again take place outside the radar installation, others are localised within the installation and can, when aggregated, be taken as representing the radar behavioural function *convert electrical energy to signals that reveal plane positions.*

The second possibility is derived from the work of Chandrasekaran and Josephson, who in their analysis of the meanings engineers attach to the concept of function, make a distinction between *environment-centric* and *device-centric* viewpoints [10], §5. In both these viewpoints (they are actually extremes since mixtures of the viewpoints are allowed) a function of a technical system refers to parts of the behaviour of the system. Yet, in the device-centric viewpoint, this reference is explicitly cast in terms of structural or behavioural features of the technical system, whereas in the environment-centric viewpoint reference is only made to elements in the environment of the technical system, including its *mode of deployment*. Note: the example Chandrasekaran and Josephson consider is the function of an electrical buzzer: from a device-centric viewpoint, its function is to make a sound when a switch is closed; from an environment-centric viewpoint, the function may be to enable a visitor to inform a person in a house that someone is at the door. One can now take the verb-noun representation of a purposive function of a technical system as an environment-centric viewpoint on the (behavioural) function of that system, and take the operation-on-flows representation as a device-centric viewpoint on the (behavioural) function of the technical system. In this way all the analyses by Chandrasekaran and Josephson of the relation between the two perspectives become available to address our design-methodological issue. In general this means that the transposition of a verb-noun representation of a purposive function of a technical system into an operation-on-flows representation of a behavioural function of that system is valid, if it can be shown that a technical system that has that behavioural function, and that is manipulated according to a specific mode of deployment, can be a means to achieve the purposive function. As such this second possibility does not provide concrete tools for making the transposition. It rather gives a richer and more complicated understanding of this transposition than the first possibility by introducing the notion of mode of deployment to the transposition: in the first possibility this transposition can be simplified to a functional-decomposition analysis of the operation-on-flows representation of the purposive function in terms of a set of more simple operations-on-flows, which is a procedure that is already described in design methodology; in the second possibility the transposition becomes finding an explanation of the purposive function, which may consist of a functional decomposition, but which also may consist of more complicated elements such as modes of deployment.

7. SUMMARY

In this paper I have considered the relations between the different meanings and representations of the concept of technical function. I have focused on two representation schemes, verb-noun and operation-on-flows representations, and analysed whether representations of technical functions created with the one scheme can be transposed into representations of the same functions with the other scheme. I have argued that the answer depends on the particular meaning of function that one adopts. When functions of technical systems refer to behaviours of the systems that contribute to satisfying customer needs, or when functions of technical systems refer to the parts of the behaviours of those systems that are intended by users or designers, then these two representations can be transposed into one another using the rule that the verbs in the verb-noun representations correspond to the operations in the operation-on-flows representations, and the nouns correspond to the (main) flows. When, however, functions of technical systems refer to the purposes for which the systems are designed, then these representations cannot be transposed using this rule. The main reason for this result is that the nouns in the verb-noun representations of purposive functions single out flows that need not necessarily go through the technical systems; this makes that purposive functions cannot, in general, be represented by operation-on-flows combinations, where the flows in these combinations are flows through the technical systems. The two examples I used to argue for this result were the purposive functions of electrical fans and of radar: the verb-noun representations of these functions are to *cool human body* and to *detect planes*, which by the transposition rule yield a human-body flow and a flow of planes which clearly do not go through the fan and the radar installation. I also briefly mentioned a specific and a general way in which verb-noun representations of purposive functions of technical systems can be transposed into operation-on-flows representations of behavioural functions of the systems. This final part of the paper is, however, of a more tentative nature. The main result of this paper is that operation-on-flows combinations where the flows are flows through the technical systems, are not suited to represent the technical functions of the systems when these functions are understood as the purposes for which the systems are designed. The usefulness of representation schemes for functions is thus dependent of the particular meaning one attaches to the concept of technical function.

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