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HETEROGENOUS CONSTITUENTS OF TECHNICAL PRODUCT AS CONSISTENT ELEMENTS OF A TECHNICAL SYSTEM

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1. Introduction

Traditional engineering design methodologies have until now mostly been focused on the mechanical constituents of the designed technical products. This has also been reflected in the related educational approaches and increasingly criticized [Albers 1997]. Four generic product categories specified in [CSN EN ISO 2002] mirror the increasing share of non-mechanical constituents in recent products:

- 'solid' *Hardware (HW)*, which is generally tangible and its amount is a countable characteristic;
- 'non-solid' *Processed Materials (FW) - 'Formless' (*according to the proposal of the author)*,* which are generally tangible and their amounts are a continuous characteristic;
- *Software (SW),* which consists of information and is generally intangible;
- *Service (AW) - 'Assistanceware' (*according to the proposal of the author)*,* which is the result of an activity performed at the interface between the supplier and customer and is generally intangible.

The German Society for Engineers has recently published a guideline for mechatronic systems [VDI 2004], which includes a 'V-model' of engineering design development (Figure 1). The traditional procedural engineering design models are obviously included here in its connecting central 'bottom part' labelled 'domain-specific design', which is situated between the two 'V arms'. These arms represent 'System design' and 'System Integration' processes. These are horizontally connected by verification, validation, and property check feedbacks at different 'levels' of maturity of the designed mechatronic product. However, no explicit joint model of the designed technical product that integrates these three 'domain specific' parallel design streams is presented, and no process and processed material constituents are (explicitly) considered in it. A model is shown in [Blanchard 2004] similar to [VDI 2004] with respect to software systems [Eder 2006].

2. HW, Processed Materials, SW, and Services as Elements of TS

The engineering design methodologies can be substantially boosted by implementing a consistent approach based on the Theory of Technical Systems (TTS) [Hubka 1988] to all the above mentioned objectively existing generic categories of technical products. This, consistently implemented concept in comprehensive engineering design theory [Hubka 1996] has already proved its power of theory and application in a series of publications [Banse 1997] by its authors, their colleagues and followers, including the author of the presented paper e.g. [Hosnedl 2001 and 2006] and many others.

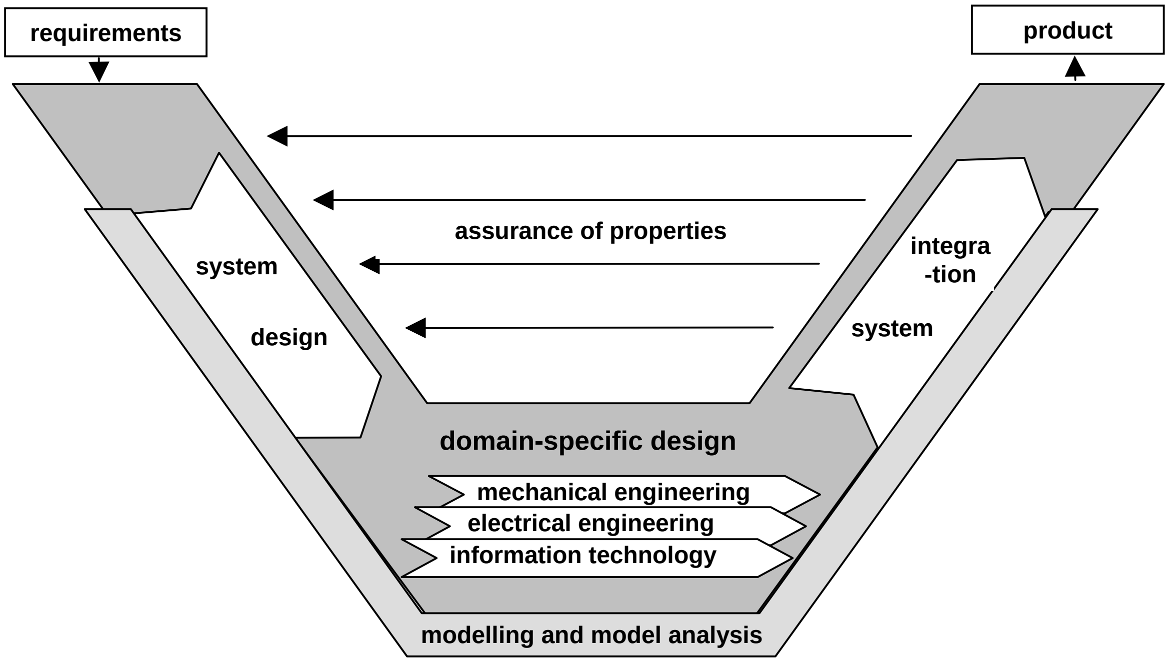

Fig. 1: General V model as a macro-cycle of the generic procedure for designing mechatronic systems [VDI 2004]

Using the concept of TTS, we can at first clearly specify all the above mentioned generic categories of a technical product as consistent elements of a Technical System (TS). We will preferably look at these categories as constituents of a 'compound' technical product. Their splitting up into the respective corresponding partial 'single category' products is then only a formal step [Hubka&Eder&Hosnedl 2007]:
- *TS hardware (HW):* the generally tangible, material TS constituent of a technical product, the quantity of which is countable; it may or may not be a technical (sub-)system with a substantial contribution from engineering (e.g. mechanical engine part, tyres);
- *TS processed material (FW):* the generally tangible, material TS constituent of a technical product, the quantity of which is not countable and can be measured only in 'bulk' units of volume, mass, energy, etc. (e.g. fuel, cooling liquid);
- *TS software (SW):* the generally intangible, information TS constituent of a technical product (e.g. driver's manual), which also includes a set of computer instructions (e.g. engine control software), carried either on embedded or transmission material media, i.e. on the corresponding TS hardware components;
- *TS service (AW):* the generally intangible TS constituent of a technical product in the form of a result of a process, which is provided by a supplier to a customer; the process may or may not be a technical process (sub-)system with a substantial contribution from engineering (e.g. operating instructions given by the salesman);

Many products comprise elements belonging to different generic product categories, as shown in the examples above concerning the product 'automobile'. Whether the product is then called hardware (HW), processed materials (FW), software (SW) or service (AW) depends on the dominant element. We can have objections to the ISO classification above, nevertheless it is a matter-of-fact that the mentioned generic categories of products exist, and also concern technical products.
At this moment all these TS constituents can be specified as elements of the TS Life Cycle (LC) depicted in Figure 2 modelled as a series of structurally identical Transformation Systems (TrfS) shown in Figure 3 [Hubka&Eder 1988]. This is essential for comprehensive specification of the requirements on all 'TS-External' (i.e. 'TS-outside reflective') LC requirements on properties and corresponding behaviours of the designed technical product, and for their establishment and realization by 'TS-Internal' (i.e. 'TS-inside reflective') properties during 'TS-origination LC phases'.

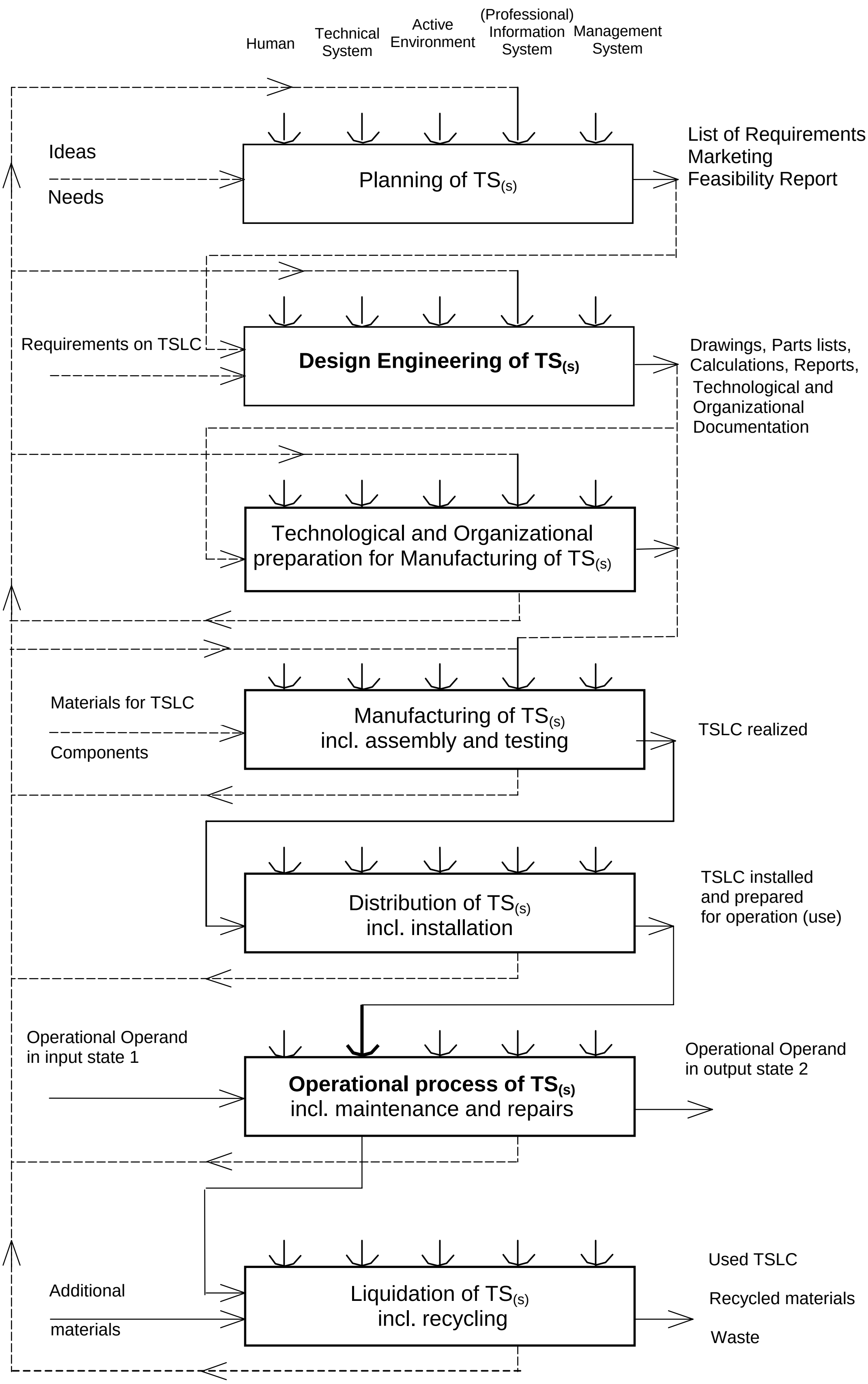

Fig. 2: General model of Life Cycle (LC) of Technical Product / System ($TS_{(s)}$) as a cycle of Transformation Processes (TrfP) and corresponding Transformation Systems (TrfS) [Hubka 1988]

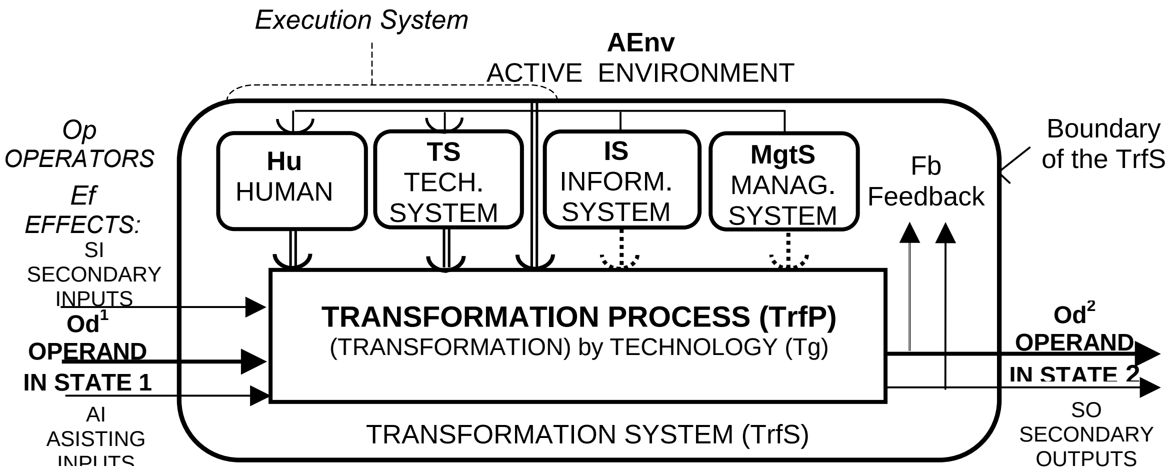

Fig. 3: General Model of the Transformation System (TrfS) with Transformation Process (TrfP) [Hubka 1988, etc.]

From the viewpoint of the '**TS-existence (and liquidation)'** domain of the LC we can now see that:

- ***TS hardware*** (HW) is a part of the TS-operator (i.e. one of the subjects performing the needed TrfP) of the Operational Process, which has traditional 'solid' constructional structure as usual;
- ***TS processed material*** (FW) is a part of the TS-operator of the Operational Process, which has a 'non-solid and dummy' constructional structure; which consists only of 'formless' materials;
- ***TS software*** **(SW)** is a part of the TS-operator of the Operational Process in the form of:
  = 'computer' algorithmic and programmed SW carried on either transmission or embedded 'computer' HW.
  = 'traditional' formalized SW, carried on either transmission carriers like paper, stickers, etc. or on embedded inform. carriers like TS labels, lettering, but also TS shapes, colours, etc.
- ***TS services*** **(AW)** are transformations (Fig. 3) provided on TS e.g. during/by distribution (sale, delivery, installation, etc. services), maintenance (after sale both guaranteed and non-guaranteed repairs, spare parts delivery, upgrading, etc. services), and, possibly, liquidation (disassembly, separation, recycling, disposal, etc. services) to the respective customers; the technical product in question thus becomes TS-operand (i.e. object of transformation changes within the corresponding TrfP) within these processes.

From the viewpoint of the **specification for realisation stage** we can now see that:

- ***TS hardware*** is completely specified by its constructional structure, i.e. by values/manifestations of property characteristics of its Elemental Engineering Design Properties; (i.e. of the TS constructional elements and their arrangement, and the respective elements by characteristics of their forms, dimensions, materials, types of manufacturing, tolerances and surface qualities – everything in general in pre-assembly and post-assembly states);
- ***TS processed*** **material** 'constructional structure' has no forms, but it can also be specified by the property characteristics of the remaining TS Elemental Engineering Design Properties, maybe in a slightly modified form (e.g. elements – constituents, dimensions - volume, etc.)
- ***TS software*** 'constructional/design structure' can be specified analogously like TS hardware 'constructional/design structure' (i.e. by SW elements/routines, etc. and their arrangement, and the respective routines by their final corresponding forms, etc.)
- ***TS service*** can be specified as a required change of the state of the TS 'constructional/design structure'. It is 'manufactured', i.e. realized e.g. during the respective transformation processes mentioned above.

From the viewpoint of the **Engineering Design Process stage** of the 'TS-origination' domain we can now see that:
All the treated categories of the technical (sub/)systems of the technical product have obvious analogies in their final specification by their corresponding 'constructional structures', which are necessary for their final implementation/realization, i.e. manufacturing, processing, implementation, etc. This can doubtlessly lead to a generally consistent integrated/ collaborative engineering design, development and realisation/implementation of the 'compound' technical products comprising constituents of two or more mentioned of the generic categories. This can be advantageously performed on the basis of the 'General Procedural Model of Design Engineering of TS' [Hubka&Eder 1996], which is theoretically supported by step by step iterative concretisation of the TS structures, beginning with the process structure, through the functional and organ structures to the (rough and full) constructional structures as shown in a simplified form in Figure 4 [Hosnedl 2006]. This procedure is both fully theoretically supported by iterative concretisation of TS structures, and can 'communicate' with all traditional procedural as well as with the 'best (and even worse) practice' engineering design strategies [Hosnedl 2006].

3. Integrated Design Engineering of Heterogeneous Technical Products

Looking now at the most usual technical products with predominantly HW constituents, we can consider that the strongest interactions arise between TS HW and SW constituents during engineering design because TS processed materials serve mostly as TS and TrfP inputs, which are not designed as such, and TS services are more or less 'attached activities', which are not directly embedded into the TS constructional structure.
Considering the roughly outlined procedure of the engineering design process above, we can see that the process and function TS structures are independent of their future realisation/implementation by TS HW or TS SW. The crucial division is made during the transition from the TS functional to TS organ structure using, for example the method of morphological matrix (Figure 5).
Here possible organs are assigned to the respective TS functions. Thus it is also right place for SW, or at least HW&SW, e.g. mechatronic function carriers, i.e. organs, to be consistently included in the designed TS organ structure (besides the traditional mechanical, pneumatic, hydraulic, magnetic, etc. principles), which is finalised in the next phase into the final (rough and full) constructional structures.
Thus the SW 'elements' can be implemented as parts of 'TS structures' on all usual levels:
- '*black box structure'* in a traditional form without any 'visible' differences
- *functional structure* in a traditional form without any 'visible' differences
- *organ structure* as 'SW (information) organs' in a form of 'procedural models/diagrams'
- '*constructional' structure* as 'SW (information) constructional organs' in a form of 'traditional written symbols (differing according to their type, form etc.), in the form of computer programmes (differing again according to their type, form, language, etc.), and maybe in other 'constructional' forms.
Thus the engineering design process of HW and SW constituents is joint until the stage of TS(s) Function Structure. After that their designs become autonomous using domain specific HW and IT tools, nevertheless they remain linked by their 'joint' TS(s) Function Structure. 'SW (information) TS modules' can also be designed, developed (we can even use the identical terms as for 'HW (tangible/mass) modules' for these activities) and used in the form of repeatable 'TS SW Elements' analogously with 'TS HW modules' (traditionally called 'Machine Elements'). This for example enables the inclusion of such 'TS SW elements' as a specific domain of the joint system of 'Technical Product Elements'. A series of further analogies enabling similar integrations exist. Of course the use of 'SW (information) organs' will probably be restricted mainly to 'control processes', but no explicit constraints obviously exist. Of course, 'SW constructional modules' must be carried by tangible HW (material) media like microchips, CDs, etc., because SW (information) itself is mass-free, however it cannot exist without mass.

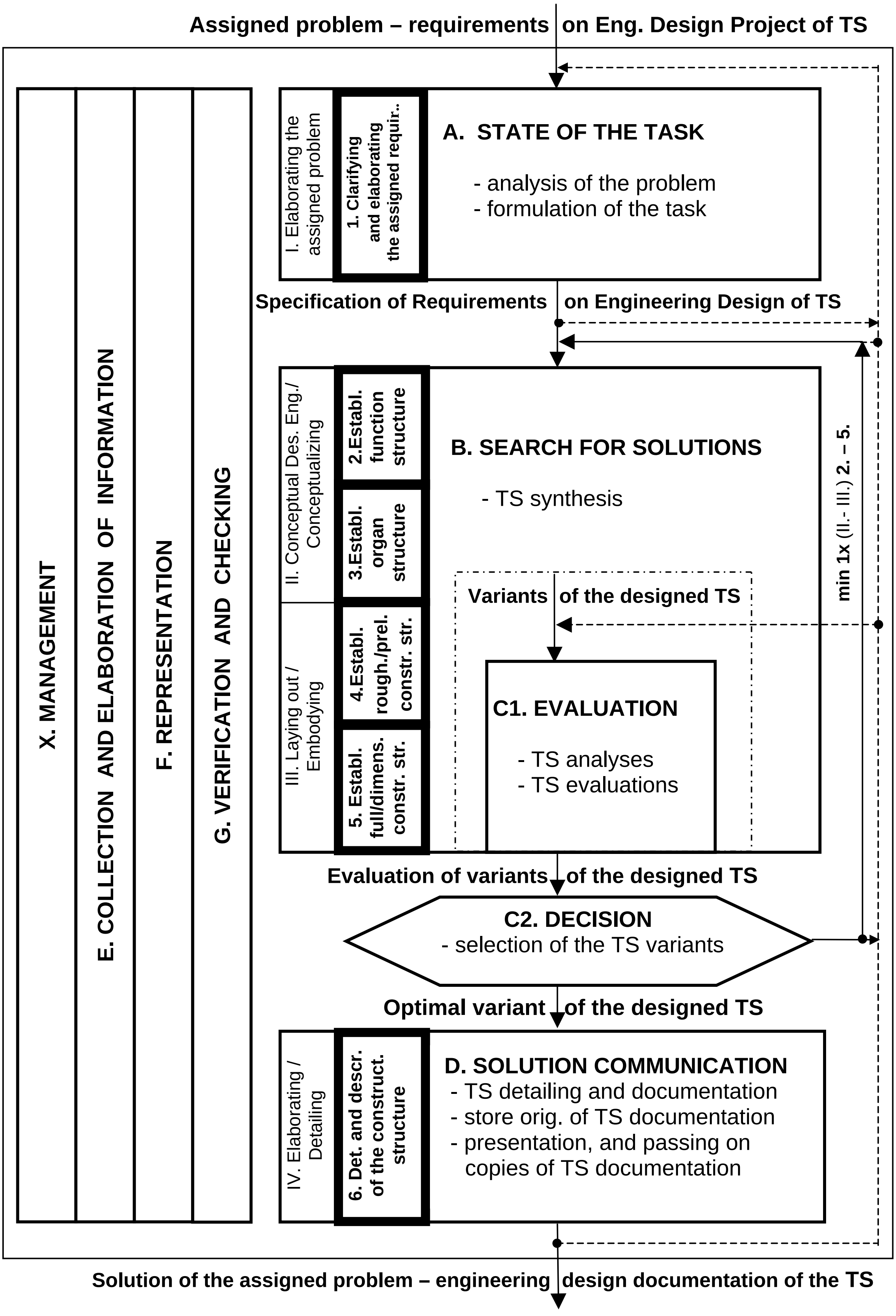

Fig.4: Basic structure of the General Procedural Model of System Design Engineering of TS 1-6 [Hubka 1996 => Hosnedl 2006]

Functions		Action principles and related Families of Organs or Organs						
		1	2	3	4	5	6	7
1	ENABLE connection with workpiece	form locking	*mechanical* screw or bolt	wedge	*Friction force locking* pneumatic	hydraulic	magnetic	
2	ENABLE rotational movement	*Rotational guidance* sliding journal bearing	rolling bearings	combined with tilting				
3	ENABLE tilting movement	cylinder	sphere	fulcrum pin	hanger from above			
4	ENABLE vertical movement	straight line guidance	screw thread	linkage	sliding bracket			
5 6 7	LOCK position states	direct by hand	*Form locking* hole and pin	ratchet mechanism	*Friction force locking* within the guidance – screw thread	screw, screw with washer	wedge, brake block	
2.2 3.2 4.2	ENABLE drives – by hand	direct	pair of gear wheels	rack and pinion	*with mechanical advantage* crossed-axis helical gears	worm and wheel gearing	band, rope, chain	lever, eccentric, cam
2.1.1 3.1.1 4.1.1	ENABLE movements regulation	through drive mechanism	through locking (ratchet)	**HW&SW**				
2.1.2 3.1.2 4.1.2	INDICATE position states	*mechanical* reference line+scale	pointer + scale	optical	electronic	mechanical stop	none	**HW&SW**

A,B,C,D

Fig. 4 Morphological Matrix with possible Organs related to the established Functions of TS, and with their considered combination – an example

These HW media are designed and realised analogously as ‘tangible (object) TS’. SW is stored on them using ROM or RW technologies, based on more or less generally known changes of their TS constructional structures, ‘beginning’ with holes in punched tapes, through changes of magnetic state of their material of magnetic tapes or discs to micro-imprints made by laser on the surface of a CD, etc.

Thus everything is again consistent with the current EDS approaches, and only ‘*SW (information) organs’* have to be considered during planning, design engineering, further origination phases, as well as in other phases of the existence and liquidation of TS.

TS(s) *processed material* constituents serve as main, auxiliary or secondary material inputs and outputs of the designed TS(s) and corresponding ‘Operational TrfS’. TS(s) *service* (e.g. distribution, maintenance, liquidation) constituents can be designed as a corresponding TrfP or complete TrfS, the operand of which is the designed TS(s) [Hubka 1996].

4. Conclusion

The outlined approach comprising all four Product generic categories [CSN-EN-ISO 2002] can obviously be implemented as integration strategy for the above mentioned *Hardware* and *Software* oriented parallel ‘Domain-Specific Designs’ (i.e. Mechanical Engineering, Electrical Engineering, and Information Technology) in the ‘V’ Model of Design Development of Mechatronic Products [VDI 2004], and, when the remaining two constituents, i.e. *processed materials* and *services* are also included, for design engineering of technical products in the full [CSN-EN-ISO 2002] context.

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References:

[Albers 1997] ALBERS, A et al. (incl. HOSNEDL. S.) Heiligenberger Manifest. Albers, A. a Birkhofer, H. (Eds.) Proceedings of the Workshop Die Zukunft der Maschinenelemente-Lehre. Heiligenberg: TH Karlsruhe a TH Darmstadt, 1997,

[Banse 1997] BANSE, G.: Auf dem Wege zum Konstruktionswissenschaft (On the path to Engineering Design Science). Cottbus: TU, 1997

[Blanchard 2004] Blanchard, B.: Systems Engineering Management, Hoboken, NJ: Wiley 2004

[Eder 2007] EDER, W. E., HUBKA, V., HOSNEDL, S.: Design Engineering, A Manual for Enhanced Creativity. CRC Press, Taylor & Franciss Group, Boca Raton, Florida USA (submitted, planned issue 2007)

[Eder 2006] EDER, W. E., Weber, C.: Comparisons of Design Theories. AEDS 2006 Workshop. Pilsen: UWB, 2006

[Hosnedl 2001] HOSNEDL, S., VANĚK, V. a BORUSÍKOVÁ, I.: Design Science for Engineering Design Practice. International Conference on Engineering Design – ICED 01. Glasgow, UK: IMechE, London, 19.-25.8.2001. Vol 3, s. 363-370. ISBN 1 86058 1.

[Hosnedl 2006] HOSNEDL, S., VANEK, V.: Engineering Design Science based Design Research for Education and Practice. In: Special Issue of the Selected Articles (4 Best Paper Awarded and 10 being come up for the Best Paper Award) of the 1st Conf. on Design Engineering and Science – ICDES2005. Vienna, Austria: Japan Soc. for Design Eng. and TU Vienna, (28.–31.10.2005, p. 63 - 68.). ISSN 0919-2948. Tokyo: Japan Society for Design Engineering, 2006, p. 31-36

[Hubka&Eder 1988] HUBKA, V., EDER, W.E: Theory of Technical Systems. Berlin Heidelberg: Springer - Verlag, 1988, (2. vyd. něm. 1984) ISBN 3-540-17451-6

[Hubka&Eder 1996] HUBKA,V., EDER, W.E.: Design Science. London, Springer,1996, ISBN 3-540-19997-7

[ČSN EN ISO 9000] ČSN EN ISO 9000 (ed. 2, 01 0300, idt ISO 9000:2000) Quality mangement systems – Fundamentals and vocabulary. Prague: Czech Institute for Standardisation, 2002

[VDI 2004] VDI Richtlinie 2206: Konstruktionsmethodik für mechatronische Systeme

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