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PROPERTIES AND QUALITY OF TECHNICAL SYSTEMS

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1. Introduction

Any technical product - technical object system (TS) and its life cycle processes needs to meet many requirements. These are not only requirements concerning the TS operational/transformation functions, their parameters and connection interfaces, but also high product safety and health protection, good appearance, easy manufacture, transport, maintenance and liquidation, low price, short delivery time, and many others.

Some of these requirements concern the TS operational process (the TS operational/ transformation functions and their parameters, etc.). Some pertain directly to the TS constructional structure (locations, forms and dimensions of connection interfaces, etc.). Some are more concerned with the TS conformance to other life cycle processes (easy manufacture, transport, operation, maintenance, liquidation, etc.). Some have to be fulfilled ‘implicitly’ within all these processes (high product safety, health protection, environmental compatibility, etc.) and some result from previous processes (low price, short delivery time, etc.). The reason for this diversity is the fact that these requirements have to cover all the important (partial, subtotal and total) TS ‘multiple overlapping’ properties related to all the TS life cycle processes.

Furthermore, only a minor part of these requirements is available to engineering designers as the explicitly stated requirements. Most of them are generally implied or obligatory [ISO 9000:2000], and very often so far inapparent, that, even for very skilled engineering designers and/or researchers, it is very easy not to consider them in time or to omit some relevant points.

2. TS properties and their states

The fulfilment of each requirement can be evaluated by comparing the required and real (future or actual) states /‘values’ of the corresponding TS property and/or TS life cycle process property (the fulfilment of all partial and subtotal corresponding requirements, if any, are necessary). These states can mostly be expressed/measured linguistically only (high, low, easy, impossible, etc. - or using their alphabetical/numerical codes). Only some requirements/properties can be measured by numerical sizing with an attached physical unit (m, s, m/s, rpm, J, W, etc.). However, some of the TS life cycle process oriented requirements (easy manufacture, distribution, required price, etc.) can also be measured by means of cost units (partial, subtotal or total costs needed for machining, assembly, packaging, storing, transport, etc., in EUR, $, etc.) and/or in corresponding time units (partial, subtotal or total times needed for the operations mentioned above in years, months, hours, seconds, etc.). The states of the TS properties, i.e. of the potential quality characteristics [ISO 9000:2000], are affected/determined both by the state of TS constructional structure and by the factors related to the respective TS life cycle processes. It is not possible to separate the share of these two complementary components on the final state of the TS property.

To be able to achieve, identify, evaluate, improve etc. the required future real states of the TS properties in engineering design processes, it is necessary to consider ideal/supposed/prescribed nominal, lower and upper 'constructional' states of the TS life cycle process factors. The respective nominal, lower and upper 'constructional' states of all TS properties (Fig. 1) can then be derived/predicted for the designed TS constructional structure within the ideal/supposed/prescribed TS life cycle processes using relevant, more or less accurate, thought and/or computational methods available. The future/actual achieved states of TS properties can be called 'real' ones (Fig. 1) if necessary. On the other hand, when speaking only about engineering design of TS (including this paper) the adjective 'constructional' can usually be omitted (except when it is necessary to differentiate both cases).

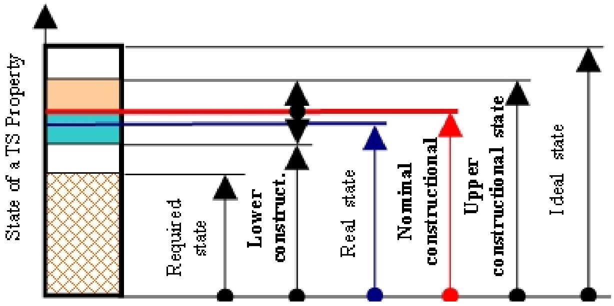

Figure 1. States of a TS property

In order to emphasise the unavoidable constructional share of TS in the constructional state of a TS property in ideal/supposed/prescribed process circumstances and/or on the resulting future/actual real state of this property, and to avoid the misunderstandings mentioned above, the TS property can be defined as a 'TS constructional suitability for a respective requirement'. Of course, having this in our minds, we can call this 'constructional suitability' simply a 'TS property', too (using the 'respective requirement' class as an adjective), e.g. TS functional, manufacturing, distribution, operational or liquidation properties, and maybe cost/economic or time properties as well. The importance of this approach proves that a good deal of the relevant knowledge has been gathered and developed into generally known sets of methods, rules, and facts called '*Design for X' (DFX)*, where X means 'TS property', i.e. actually 'TS suitability for a respective requirement/property X'.

3. Strategies for the consideration of TS properties

The solution space for the required/considered and unforeseen TS properties and both their internal and external relations mostly depend on the knowledge and experience gained through education as well as practice. Furthermore, they are strongly affected by the previously made and corrected mistakes. This approach, abstractly depicted in the bottom plane in Fig. 2, can be called *intuitive strategy* (level I) of using the needed knowledge.

A better procedure is the use of theoretical and/or empirically prescribed guidelines. These identify, more or less, among other things, the range of properties to be considered/required as depicted in the middle plane in Fig. 2. However, a buffer space has to be allocated here for those properties which have not been considered/required by the methodical guidelines available and which do not 'emerge' until the process of engineering design of TS or unfortunately very often later or even too late. This procedure can be called *methodical strategy* (level II) of using the needed knowledge.

In our opinion and experience, knowledge needed for engineering design of TS can be best used in engineering design education, practice and research in the form of the system of easy to remember concise systemic graphical 'maps'/schemes/models [Hubka 1996], including also the knowledge concerning the TS properties. Such a map concerning the classes of internal and external life cycle TS properties (understood as TS 'suitabilities' for respective requirements as mentioned above) is abstractly depicted in the top plane in Fig. 2, and discussed briefly in the following chapter.

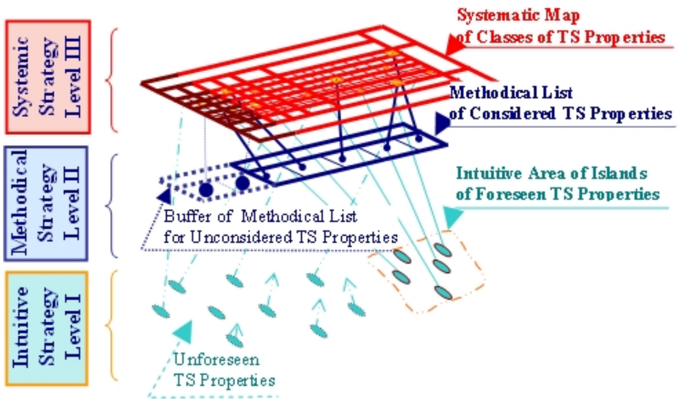

Figure 2. The solution spaces for TS Properties using different strategies of use of needed knowledge

This approach can be called a *systemic strategy* (level III) of using the needed knowledge. Even if not perfect, it can provide, in most instances, a comprehensive framework and controls for ensuring the required course leading to the 'goals', and at the same time for maintaining 'balance' of the 'goals' when designing any new TS. This philosophy supports also very effectively the necessary optimal transitions between systemic, methodical-empirical and intuitive ways of thinking (i.e. transitions III <=> II <=> I), which can be called *Knowledge Integrated Engineering Design*.

4. Classes of TS properties

In the past (before Releaux) it was believed that there were countless numbers of classes of TS properties, which were, moreover, different for respective areas of the TS. In such a case the required/considered TS properties of the designed product can depend on the use of intuitive knowledge support at level I or on the use of methodical support at level II only.

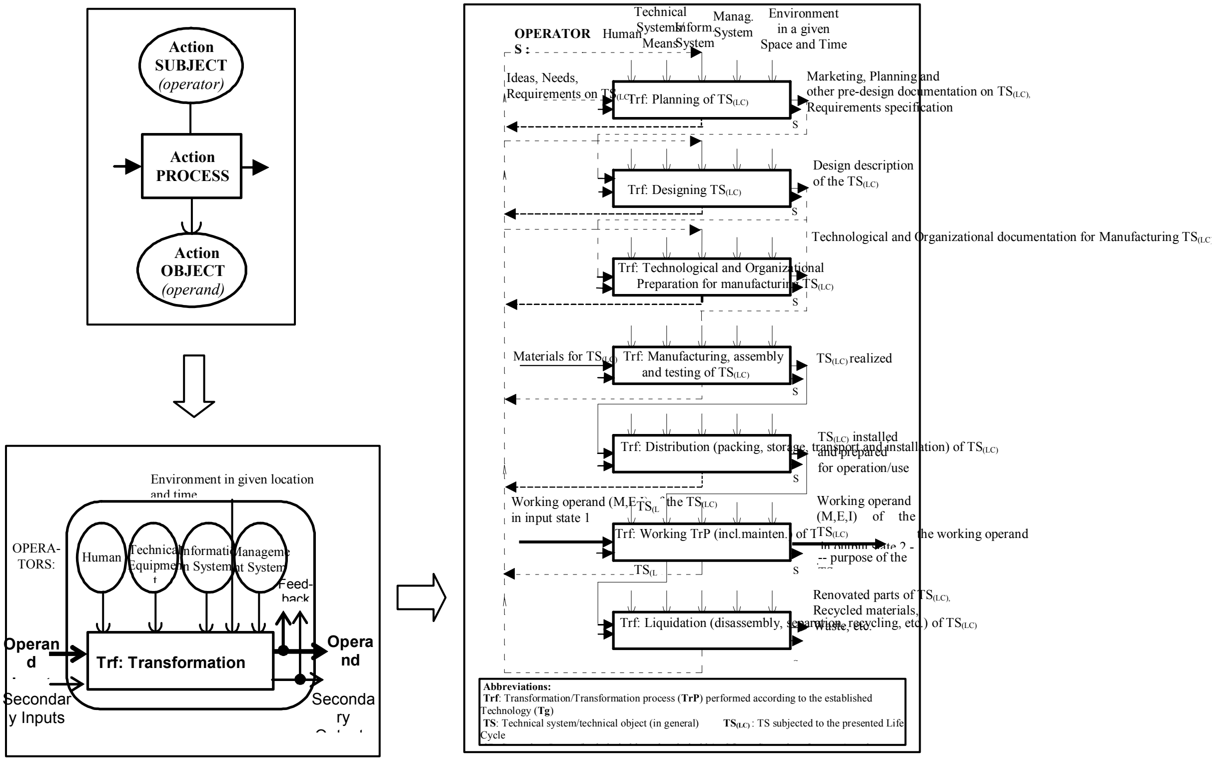

Figure 3. Model of TS Life Cycle [Hubka 1996] (right) composed from the Models of Transformation Systems [Hubka 1996] (bottom left), paradigm of which creates a Model of Action [Eekels 2000] (top left)

However, the TS properties and their relations exist objectively, i.e. independently of the minds of engineering designers, customers, researchers, etc. It is, therefore, optimal to develop a complex and self-consistent system/'map' of 'all' classes of the existing TS properties at level III as mentioned above.Our hypothesis was to derive classes of the so called external TS life cycle properties objectively using the model/'map' of TS life cycle phases and to add to them the classes of so called internal TS properties, which can be defined axiomatically [Hubka 1996].

CLASSES OF EXTERNAL TS PROPERTIES
TS PROPERTIES RELATED TO TS LIFE CYCLE (LC) PHASES / PROCESSES
Properties for Planning - constructional suitability for company's product, production, human, technical, information/knowledge, license, market, sales, service, etc. policy, constraints and identity
Properties for other Origination Phases – constructional suitability for the required engineering design, technological and organisational preparation of manufacturing, manufacturing (incl. co-operations, purchasing, assembly and testing), etc.
Properties for Distribution – constr. suitability for required packaging, storage, transport, etc.
Function Operational Properties or (more generally) *Effect Properties* on the transformed operand– constructional suitability for required clamping, moving, heating, etc. *(including their functionally determined properties/parameters–* constructional suitability for required power, speed, rpm, etc.*)*
Other Operational Properties – constructional suitability for required operational safety, space and energy needs, service life, reliability, etc.
Properties for Liquidation – constr. suitability for required disassembly, separation, recycling, etc.

Figure 4. Part A Process related Classes of External Properties of Technical System (TS) based on the TS Life Cycle model (Fig. 3)

TS PROPERTIES RELATED TO OPERATORS OF THE RESPECTIVE TS LC TRANSF. PROC.
Properties for Humans – constructional suitability for required operator safety, ergonomics, agreeability to humans, including aesthetic appearance, low noise, etc.
Properties for other TS – constructional suitability for required use of easily accessible TS, few demands on needed new technical means/TS, etc.
Properties for Information – constructional suitability for required needs of easily accessible/provided information/knowledge, etc.
Properties for Environmental Material and Energy – constructional suitability for required ecology, i.e. society, nature and space, etc., compatibility
Properties for Environmental and Management Information – constructional suitability for keeping laws, regulations, required culture, customs, etc.
Time Properties for Process Management – constructional suitability for keeping required deadlines (including delivery time), duration of processes/operations, etc.
Economic Properties for Process Management – constructional suitability for required production, operational cost/price, effectiveness, etc.
CLASSES OF INTERNAL TS DESIGN PROPERTIES
General Design Properties –TS strength, stiffness, hardness, corrosion resistance, etc.
Elementary Design Properties – TS structure, and shapes, dimensions, materials, types of manufacture, tolerances, surfaces quality, etc., of its elements
Design Characteristics – TS working principles, crucial functions, features, etc.

Figure 5. Part B Operator related Classes of External Properties of Technical System (TS) based on the TS Life Cycle model (Fig. 3) and Classes of Internal TS properties according to [Hubka 1996]

The chosen way for the development of theoretical model/'map' of TS life cycle using models from [Eekels 2000 and Hubka 1996] is depicted in Fig. 3. The resulting system of classes of external TS properties has the simple table form shown in Fig. 4. The important feature is that the part on the top of Fig. 4 - Part B related to operators represents 'columns' of the matrix, the 'rows' of which are 7 life cycle processes shown on the right of Fig 3. The classes related to the operational process, and environment and management operators have been doubled in Fig. 4 because they each have two significant different roles.On the other hand the 'theoretical' classes related to engineering design, technological & organisational and manufacturing processes have been merged here to only one class due to their close relationships. The complementary system of classes of internal TS properties [Hubka 1996], which are carriers of all the inherent TS external properties related to the mentioned classes, is shown in the bottom of Fig. 4. To summarize, the presented system/"map" of the classes of TS properties includes 13 external (6 process related + 7 operator related) + 3 internal (i.e. 16 altogether) simply to understand and remember 'categories' for classes of TS properties only. However, due to the matrix form of the operator related classes it covers 6 + 7 x 7 + 3 = 58 (in fact only 55 due to the irrelevance of some intersections within the mentioned matrix) real classes of TS properties.

Considering both general and actual priorities of classes of the TS properties (mostly the operation and safety related classes of TS properties, typed in bold, have the highest priorities) this system/'map' can effectively serve as a reference for the establishment of the systematic list of requirements on designed TS and for all other related engineering design activities.

5. TS properties and required Quality, Cost and Time

When looking at the TS properties from the point of view of 'TS constructional (or real) suitabilities' for the required states of *Quality, Cost and Time* (affected by the ideal/assumed/prescribed or real factors of relevant processes), we gain very transparent relations to the relevant TS properties (however, many of the TS properties can easily be omitted when assessing them using the above mentioned strategy levels II or even I) and thus to engineering design of TS. We can even gain a general understanding of this 'triad':

- *The TS constructional (or real) suitability for the required TS Quality* can be evaluated, as a result of the partial evaluations of ratios of the constructional (or real) and required states of achieved actual and potential future required TS properties (quality characteristics according to [ISO 9000:2000]) beyond the considered stage of evaluation (the Quality of the designed or implemented, etc., TS concerns all the required TS properties [ISO 9000:2000] related to the ideal/assumed (or real) state of the TS constructional structure and ideal/ assumed/prescribed (or real) states of all the following TS life cycle processes and their operators, which can be easily performed using the table in Fig. 4).
- *The TS constructional (or real) suitability for the required state of Cost* can be evaluated as a result of the particular evaluations of ratios of the constructional (or real) and required states of cost results related to all the relevant preceding (related to the considered stage of evaluation) TS external properties (i.e. those concerning all the previous TS life cycle processes and their operators, which can be also easily performed using the table in Fig. 4).
- *The TS constructional (or real) suitability for the required state of Time* can be evaluated as a result of the particular evaluations of ratios of the constructional (or real) and required states of time results related to all the relevant preceding (related to the considered stage of evaluation) TS external properties (i.e. those concerning all the previous TS life cycle processes and their operators, which can be easily performed using the table in Fig. 4 too).

It is interesting that the term 'required' can be generally understood as related to any past, current or future stage of the TS life cycle and may, surprisingly, be seen from any of its past, current or future stages (i.e. the same or a different one). When the term required is specified by the term 'delivery', we obtain the three special expressions generally known from the market as *Quality, Cost and Time* only.

6. Conclusions

These results have been significantly affected by the works of Andreasen [Andreasen 2000], Hubka [Hubka 1996] and many others, mostly the members of the Design Society formerly the WDK society (see references). Our analyses proved that 10 publications from the mentioned references present from 7 to 28 (in average 16,2) classes of the TS life cycle properties, which include from 16 % to 80 % (where on average 28,9 % is explicitly defined/stressed and 20,6 % is mentioned generally only) of the TS properties covered by the presented system/'map' shown in Fig. 4. On the other hand, all these reference publications cover altogether 96% of the properties (where 78% is explicitly defined/stressed only) covered by and defined/stressed in the presented system/'map' and, what is important, do not mention any TS property, which cannot be included into this system/'map'.

Besides these achievements it is important that the presented graphical model based approach (compared to the difficult to remember 6 enumeration based and 4 methodical schema based approaches in the mentioned reference publications) is user-friendly as explained above. Even if certainly not perfect it can be effectively used in engineering design research, education and practice at all levels from executive to top management. It has already been applied and its usefulness proved in more than 100 university engineering design diploma theses, which have been undertaken for almost 30 industrial companies and successfully evaluated by their reviewers. Further the presented system proved its practical applicability in almost 30 successful engineering design projects in 10 industrial companies.

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