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# TRIZ and Systemic Transitions

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## Abstract

In this paper, we compare systemic transition concepts of (large) technical systems, which are particularly important in the TRIZ theories of evolution of engineering systems, with transition concepts on the sustainable management of ecological systems. The similarity of the problem situations results mainly from the fact that in both areas *existing* systems should be further developed, whereby contradictory, interest-based requirements have to be transformed into a *functioning* «world model» in order to *implement them practically*.

The considerations are based on earlier own work, in which already a detailed concept of socio-technical systems was developed, but differentiate more strongly between processes of decision preparation and decision making. We underline the engineering quality also of management processes and on this basis propose a uniform TRIZ-methodical approach to the processes of decision preparation and decision making, that supports connectivity of models in even more complex situations.

Keywords: *technical and ecological systems, decision preparation, decision making, transition management*

## 1 Introduction

TRIZ is a systematic innovation methodology that resolves contradictory requirement situations using defined abstraction patterns (principles, standards, trends) to embed the problem into larger contexts and exploit the potential of analogy solutions to identify transition paths from the deficient technical systems to systems without the identified contradiction with the pretension that this transition can be implemented under the given *real* conditions.

Similar questions are also raised in the context of sustainability debates for socio-ecological and socio-cultural systems, see for example [1], [2]. It is generally assumed that those differ from socio-technical systems mainly by the fact that they are not «built by purpose» but work «naturally». A synopsis of corresponding investigations [3], which we created in the context of a *seminar on systems science*, shows, however, that this assumption is misleading for the following reasons:

1. The *interest* in resolving contradictions in socio-ecological systems is essentially determined by the purposes and interests of human activity, and the proposed solutions for system transitions are oriented on such activities.
2. The socio-ecological systems under consideration have been transformed by human activity for thousands of years. This socio-cultural character of the systems, that is largely ignored in the subject of relevant work and reduced to the

study of historical management practices of infrastructures, moves such systems closer to technical systems in the sense that also such systems are controled by a symbiosis of description and enforcement forms.

3. The proposed transition concepts have clearly technical character in the sense that socio-cultural processes *are designed* with methods largely adopted from engineering approaches, even if the difference between *justified expectations* and *experienced results* reminds rather the nursery times of the industrial age.

Also in TRIZ applications during the last 20 years a clear topic shift can be observed. While the theory and practice of TRIZ in Altshuller's times was strongly directed towards small technical inventions and driven by the social underestimation of systematic innovation methodologies (in both East and West), this has changed nowadays at least in leading industrialised countries. Systematic innovation methodologies play an increasingly important role in large companies in the course of innovation management. In maturity models such as CMMI description forms and business *models* play a central role. To implement such models, companies have to formulate description forms of their own processes (CMMI Level 2 «managed»), to make processes manageable through standardization of language (CMMI Level 3 «defined») and finally to feed back processes to own practices using structured data collection (CMMI level 4 «quantitatively managed»). Only on this basis optimization and technological change processes (CMMI level 5 «optimizing») can be designed as structured transition processes.

This changes the always in TRIZ weakly defined concept of a *technical system* fundamentally from an understanding of improvement and evolution of type-like consumer goods primary produced for a mass market, as they still characterize the majority of the examples in [4], to the transition of large technical systems that exist only as unique specimens, see [5], and are closer to the character of socio-ecological systems than technical artefacts of a mass market. Moreover, essential contradictions in socio-ecological systems, that result from differences between long-wave «natural processes» and short-wave socio-economic rationalities, reproduce themselves as contradictions between investment and operational dimension of those socio-economic processes, between the need for technical innovation as a long-term survival condition of the business as a whole and the short-term necessity, to earn the necessary «small charge» for that in the operating business. This internalization of external social contradictions into the development of the internal corporate logic is a key driver of development, nowadays addressed under the heading *TRIZ and Business*. In the specific conditions of action of the GDR inventor schools in the 1980s these conditions were already present, so it is no surprise, that this experience earned attention in technologically more advanced socialist states such as the former Czechoslovakia. See [6].

It is therefore time to draw these parallels between the challenges of modern company development and the challenges of socio-ecological transformation processes in more detail. It's my belief, that TRIZ as systematic innovation methodology can contribute to both topics and thus build a bridge between the sustainability discourse, which sharpens goals without realistic ideas about the appropriate tools, and an industry discourse[1], which focuses on the development of

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[1] This is centered around the term «STEM» – Science, Technology, Engineering, Mathematics. This English version addresses with the two terms «Technology» and «Engineering» the description and enforcement forms more clearly than the German version «MINT», which stands for mathematics, computer science (informatics), natural

human resources as «tools» and qualifications only («We are running out of experts»), without formulating clear goals of long reaching target corridors of societal development.

This paper summarises considerations in this regard, which originate from the comparison of transition concepts of TRIZ and transition and resilience concepts in socio-ecological and socio-technical systems research in the sustainability discourse.

## 2 On the Concept of a System

Operation and use of technical systems is a central element of today world changing human practices. For this purpose planned and coordinated action along a division of labour is necessary, because exploiting the benefit of a system requires its operation. Conversely, it makes little sense to operate a system that is not being used. Closely related to this distinction between definition and call of a function, well known from computer science, is the distinction between design time and runtime, that is even more important in the real-world use of technical systems based on the division of labour – during design time, the principal cooperative interaction is *planned*, during the runtime *the plan is executed*. For technical systems one has to distinguish the *descriptive forms,* interpersonally communicated as *justified expectations,* and the *enforcement forms*, interpersonally communicated as *experienced results*. The argumentation in this section recapitulates [5] and is explained there in more detail.

In addition to the description and enforcement dimension, for technical systems the *aspect of reuse* also plays a major role. This applies, at least on the artifact level, but *not* to larger technical systems – these are *unique specimen*, even though assembled using standardized components. Also the majority of computer scientists is concerned with the creation of such unique specimens, because the IT systems that control such plants are also unique. In this work we concentrate especially on such large technical systems and their parallels to design issues of socio-ecological systems.

The special features of a technical system are therefore mainly in the area of *interplay of components*, where one has also to distinguish between the description form (modeling) and the enforcement form (operation in the context of the various large-scale technical systems). While in the planning and modeling phase there still remains open much freedom for changes, the enforcement form is characterized by significantly higher inflexibility. Although here too the world is more complicated than getting caught up in a dichotomy like this – who dares to change a plan which has already been approved by the high chiefs – we are working with such a concept of «reduction» in the following.

This brings together essential elements to serve as basis for a *concept of a technical system*, which in a planning and real-world context is four times overloaded:

1. as a real-world unique specimen (e.g. as a product, even if the unique specimen is a service),
2. as a description of this real-world unique specimen (e.g. in the form of a special product configuration)

and for components produced in larger quantities also

3. as description of the design of the system template (product design) and

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sciences, and technology.

4. as description and operation of the delivery and operating structures of the real-world unique specimen systems produced from this template (as plans of production, quality assurance, delivery, operation and maintenance).

*Technical Systems* in such a context are systems whose design and use are influenced by cooperatively acting people on the basis of the division of labour, whereby *existing* technical systems are normatively characterized at description level by a *specification* of its interfaces and at enforcement level by their *guaranteed specification-compliant operation*.

The same applies to the description form of «natural» systems, which are also modeled in a structured way as *systems of systems* – as systems consisting of components, which in turn are modeled as systems, whose *functioning* (both in a functional and operational sense) are presupposed for the currently considered system level.

The (more general) concept of a system in such a concept has the epistemic function of (functional) «reduction to the essential». This reduction takes place in the following three dimensions, see cite [3, p. 18]

(1) External demarcation of the system against an *environment*, reduction of these relationships to input/output relations and guaranteed throughput.

(2) Internal demarcation of the system by combining subareas as *components*, whose functioning is reduced to a «behavioral control» via input/output relations.

(3) Reduction of the relations in the system itself to «causally significant» relationships.

It is further stated there that such a reductive description service rests on preexisting (explicit or implicit) description services in three dimensions:

(1) An at least vague idea about the (working) input/output services of the environment.

(2) A clear idea of the inner function of the components (beyond the pure specification).

(3) An at least vague idea about causalities in the system itself, i.e. one that precedes the detailed modeling, an already existing idea of causality in the given context.

(1) and (2) can in turn be developed in systems theory approaches to describe the «environment» and the components (as subsystems), with which the description of *coevolutionary scenarios* in turn becomes important for deepening the understanding of (3).

In this section the notion of a system was sufficiently outlined *structurally*. We use such an understanding in the following as basis for both the description and the enforcement forms.

## 3 System Dynamics

It remains to outline the *procedural* dimension of that concept, as it also plays a role in the mathematical theory of dynamical systems. The principally reductionistic character of the description form forces to build in a difference between theory and practice as difference between theoretical prediction $v(t)$ and practical development $p(t)$ of the processes themselves. Both reside on the side of the *description form,* in which $v(t)$ expresses *justified expectations* and $p(t)$ the *experienced results,* reduced to the description form *in the model*. As in the theory of dynamical systems, we start from a phase space Φ, in which the two processes $v:T\rightarrow \Phi$ and $p:T\rightarrow \Phi$ evolve in time, assuming $\Phi$ as a metric space to be able to express the *size of deviation* $d(t)=dist(v(t),p(t))$ between prediction and real development.

We further assume that $v(t)$ can be described through *movement equations*, which approximate a *temporal progress* of the process and whose solutions are close to a steady state equilibrium (attractor). From the theory of dynamic systems it is known that the geometric shape of such an attractor can be sufficiently complicated even for simple dynamic systems.

By analogy with Holling in [7] we further assume that the system dynamics $p(t)$ are influenced by the effect of restoring forces and usually moves in the vicinity of this attractor and thus $d(t)$ remains small as long as there is room on the attractor for further development (Holling's $r$ phase). This development potential exhausts itself when the system goes into a local extremum of the attractor – the system reacts on disturbances returning to the same reference point on the attractor (Holling's $K$ phase). So disturbances build up, the system status moves further away from the attractor, the near field influence of the restoring forces fails and the system «moves» to «search» for a new, often distant reference point on the attractor (Holling's $\Omega$ phase). On this distant new reference point a modification of the system's structure and dynamics are required according to the new parameters (Holling's $\alpha$ phase), and after that modification the system enters another longer stable development phase (Holling's next $r$ phase).

At the core of the problem of systemic transition concepts is the question, to which extent such conversion processes of systems propagate in a causal network of interconnected systems, whereby this network of systems arises from a double reduction of the real-world totality — not only from a reduction of the complexity of the description form, but also from structuring processes of the enforcement form, which is implemented according to the description form, the *attempt* to shape cooperative actions together along reasonable expectations.

## 4 Transition paths

In [2] a number of types of transition paths are described, which can be taken during phases of system reconstruction. This can be considered as an attempt to introduce some structure in the $\Omega$-$\alpha$ conversion phase, not elaborated further in [7]. Also [2] remains largely on a phenomenological level and develops little conceptual insight to think together social, economic and technical developments. [2] also does not go as far as TRIZ evolutionary approaches, that explicitely formulate development laws or at least patterns.

In the understanding developed in the last section, the need for system reconstruction is given if the *local* development possibilities on the system attractor are exhausted, because the system with progressing «idealization» moved into a local extremum of the attractor (Holling's $K$ phase), in which external disturbances shake up and drive the system into an unstable state (Holling's $\Omega$ phase), from which, through reorganization (Holling's $\alpha$ phase), the system reaches a new reference point, far from the original one, on the attractor.

Such a system change puts a greater stress on systems, connected with this system (components in the system, sibling components in the supersystem, general «unsystematic» relations to other systems). In this sense, systemic restructuring processes migrate along the causal systems' relationships more or less far through the network of systems.

Conversely, the disturbance stress resulting from other causally connected systems influences the system we focus on, whereby in the classical approaches the relations system-supersystem (or system-«environment») and system-component usually are considered separate from general relations (such as between the components within one system or – the same picture on another level – between subsystems of a supersystem). In [3] we did already mention that such a special consideration of micro- and macroevolution makes sense only in relationships between systems, which operate on clearly different eigentime scales: For the «fast» system the slow one can be considered in a first approximation as static, whereas from the perspective of the «slow» system the fast one can largely be considered as free of disturbances and thus described in a deterministic or at least stochastic way, since disturbances of the fast system are averaging on the time scale of the slow system.

Here too, we use a causal model in which a system-supersystem relation is not singled out, but is rather replaced by a network of causal dependencies as a directed graph. This simplifies in particular the process of trimming (TRIZ-Trend 3 in [4]), but replaces the *one* supersystem by the possibility to declare *several* causally preceding systems as «supersystems» and allows to postulate *several purpose driven* relations ruling the behaviour of the system under consideration. If we nevertheless use the notion of system-supersystem relation in the following, then always in the sense that we concentrate on *one* of these causal relations and consider it separately.

If we look from such a perspective at the arguments in [2] and [7], first the strong agent-based approach of the former work attracts attention. Agents are also available in Holling, see for instance [7, Tab. 2], but [2] with the notions «agency», «regime», «organisation» and «institution» has a clearly different focus. With all four terms, which are largely used synonymously in [2], the focus is on the organization of *processes* and not of the system's *structure*, without, however, in any case precisely defining the systems under consideration. Rather, the system and its boundaries in the three (or four) reduction dimensions of descriptive complexity, identified above, are formatting «itself» out of their movement.

In such a «panta rhei» approach [2, p. 401] the source of disturbance and the location of the reconstruction are to be distinguished. This well harmonizes with our modeling approaches developed above. But the typology intitally developed on this basis [2, Fig. 2] originates in an empiricism that is difficult to map to our model approach. This is later also admitted by [2, p. 402]: «empirical levels are not the same as analytical levels in MLP».

The «organisational levels» which are further brought in [2] into the argumentation – individual, organizational subsystem, organisation, organisational population, organisational field, society, world system – concentrate mainly on the institutionalised structures of the *organizational structure* of the respective systems (for example the «System Society») together with its Luhmann «codes», in which those systems *are literally able* to communicate about disorders at all and to decide at least roughly whether we are faced with an «incremental, radical, system or techno-economic» type of disorder aka «innovation» and how to react to this in a type-appropriate manner.

If a «conjuncture of multiple development» [2, 3.2.] is significant, then the thesis of the source of the disturbance in a single system becomes already fragile, if that disturbance is propagating wavelike in the network of systems and so it is hardly to distinguish whether this «wave» was triggered by a point source or is an emergent phenomenon of the network (which itself can be regarded as a system, but on a different level of abstraction) as a resonant response to an external disturbance. That especially in times of profound technological upheavals such emergent phenomena in complex hierarchically structured organisational networks could not left out of consideration is as clear as theoretically difficult to grasp.

To make matters worse, in such transitions three spheres interact substantially:

- The sphere of description forms (the socially available operational knowledge),
- The sphere of the real existing, in systems structured reality (the institutionalised operational procedures) and
- The cooperative subjects (with their «private» operative procedural skills).

Between spheres 1 and 2 there are *causal m:n*-relationships[2], *practically* mediated by sphere 3.

The three «kinds of rules» ([2, 3.3.] – the term «institution» is deliberately excluded here – ibid. p. 403, footnote 1), driving such a mediation in a «model of agency», are identified as the basis of a common «interpretation of the world» of concrete cooperative subjects, which has to prove itself useful and has to be mounted in the *actions* of those structures («use rules», «rules are not only constraining but also enabling» [2]). These are the forms in which the *pragmatics* between the spheres 1 and 2 are mediated and thus *conceptualisation processes in the real world* are induced up to the «conceptualisation of sociotechnical landscape» that «... forms an external context that actors cannot influence in the short run» [2].

This renders the argumentations in [2, Fig. 4] in their absolute claim of an «environmental change» questionable, since entries such as «low» and «high» [2, table 1] only make sense against clear etalon sizes, thus implicitly eigentimes and eigenspaces of a supersystem serve as reference (or, if you refer as in [2] only to the operational organization of interacting systems, such a reference system is still to be developed or must be identified). I note only in parenthesis, that this «environmental system» must be considered as culturally transformed since at least 10000 years. Such a containment is then tried to be described with notions as *frame* or *closure* [2, p. 405], but on a rather simple level of direct transformative effect of different growth rates as in the TRIZ trend 9 of «unequal development of system components» [4]. In other examples it is shown, however, that inequalities in the allocation of resources are often used by actors *to prevent* transitions. The emergent effect then may be a declining performance of the overall system. Even the described competition on the basis of different growth rates on the emergence level of the overall system can have the opposite effect, as Marx argues with his law of falling profit rate (no matter whether this law really works or the arguments have to be considered differently in a dissipative system context).

This allows to relate the six transition patterns $P_0$ to $P_5$ in [2] to Holling's model of adaptive cycles in [7] in the following way:

**$P_0$:** The system is in the *r* phase and can absorb the pressure for change from one of its components («no external landscape pressure»). The same remains correct if the pressure comes «from outside» (i.e. from other systems) and is not too big.

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[2] Description forms are based on the principle of *unity in diversity*, the enforcement forms combine diversity of such of analytical units and thus gain back *variety from unity*. I'll come back to this question at the end of this essay.

**$P_1$:** Pressure from «outside», no pressure from the components, the system is leaving or beyond the *K* phase. The system can react only reorganizing the internal relationships. The authors are largely puzzled, but mix up also two modes:

1. The system is already in the *α* phase of its own conversion processes.
2. The system is in transition to the *Ω* phase.

The example (Danish hygiene transition) is clearly one for the dynamics of the *Ω* phase, which on the TRIZ side corresponds to a transition from one S-curve to another one. How that works, however, is not understood there either. The example follows a model where the system is reorganized, but the exported function is not changed or even improved.

**$P_2$:** The system is disassembled, its components are reorganized differently. As typical accompanying phenomenon a «vacuum» is diagnosed, just as it appeared as power vacuum during the collapse of the Eastern bloc. The example given in the text does not take into account that the new conditions (automobile replaces transport by horses) have already been structurally developing in the subsystems for some time – «in the bosom of the old society». In the example the Kondratieff wave dynamics around 1890 are not taken into account.

**$P_3$:** The pressure does not come from the environment, but from individual components. The system can reorganize itself in such a way, that the external conditions, required for the reorganization of the components, can be ensured, without giving up the functionality of the system as a whole to the outside world. The explanatory potential is weak. First, «avalange change» and «disruptive change» as «landscape pressures» exist all the time as «disturbances» and secondly, are not causal here, although possibly triggering. In the example the effect of the Kondratieff wave around 1890 is also not considered. Also «market cleansing», typical for such transitions, are not discussed, resulting from productive roll-out of new technologies on a larger scale, that requires larger amounts of advanced capital.

**$P_4$:** Components in *Ω* phase meet a system in *α* phase. Actually, however, the transition is triggered from a causally deeper technology level, that effects *many* components and puts them into *Ω* phase, but which is absorbed by the system in *α* phase (and thus in a particularly flexible *r* phase). So also the example.

**$P_5$:** Unlike $P_4$, the changes can *not* be absorbed in the system and are forwarded. This means that also the relationships of the system to the external worl become unstable. The authors are quite helpless (they propose a «sequence of transition pathways») and have no example at hand.

In general, it is noted that such complex processes not only can't be explained monocausally, but also the variables in a mathematical description model cannot be divided into dependent and independent ones. Therefore one can only speak about *evolutionary patterns* [2]. The process theories referenced in the further argumentation with a focus on event chains in temporal and causal concatenation, do not, however, reflect *structural moments*, which can be extracted with advanced mathematical methods even in more complex structured phase spaces.

Giddens' approach of «rules as structures, which are recursively reproduced (used, changed) by actors» – see [2, S. 415] with reference to [8] – points in a direction, where such structural findings have to be combined with descriptions of enforcement forms of concrete cooperative subjects on different levels of abstraction, but requires at the same time a much more extensive dynamisation also of the description form, in order to express the associated non-linear feedback effects literally.

## 5 Adaptive and Transitional Management

The transition paths discussed in the last section have a significant epistemic problem – the problem of an external standpoint from which description forms are developed in order to influence real-world processes of change.

[1] suggests a completely different approach here, in that description and analysis forms are developed (with methodological support) by the actors themselves. The approach nevertheless follows classical TRIZ methods of modeling, by first identifying a supersystem as the context for determining the purposes of the system under investigation, and then modeling the system itself more precisely. But that modeling is not understood as an external process, but rather as consensus building of common description forms by the stakeholders themselves, without which cooperative action is not possible (see the concert example in [5]). This modeling process thus becomes also a *political* process, since as a result of that process not only commonly recognized description forms are expected, but *institutionalized operative procedures*. The former (recognized description forms) is prior to the latter first of all in the sense that contradictory requirements must be *articulated* before these contradictions can be resolved. This also corresponds to the two phases of the TRIZ process (in the OTSM-TRIZ version).

In such a model, two dialectical principles are already built-in,

(A) the dynamic further development of the model itself along the differences between justified expectations and experienced results of the enforcement form – including a possible wide stakeholder landscape (TRIZ trend of «completeness of the parts of the system») and

(B) the further development of the purposes in the (cooperative) supersystem, in which the system itself appears as a component («stakeholder») and contributes to the enforcement form only via its specified interface.

The former is the focus of *adaptive management*, the second of *transitional management*. In both cases the further development of the description form is part of the enforcement form.

Thus [1] is in a certain sense orthogonal to [2], bringing *the inside* of a transition phase into a methodical framework. Of course, the question immediately arises, for which transition types in [2] this methodical framework is useful or whether here again a concept is proposed as «on size fits all».

Both approaches differ further in the strategy of complexity reduction. While adaptive management considers a variety of *different* functional parameter in the concrete expression in a local context of a *unique specimen*, on the level of *transitional management* a reduction takes place based on a *functional principle*, according to which *similar* functional parameters are bundled together (e.g. «energy supply of the future», «water pollution control», «biodiversity»), to understand this principle more precise and in greater detail. While the latter follows more the motto «think globally», the the former is in the perspective of «act locally».

We met such a phenomenon of different bundling already above in the causal relationships of spheres 1 and 2 (the description forms and the systemically structured reality). This phenomenon is also well known from the component technology [9] – the *design* of components is done by bundling *similar* requirements from *different* sources, the *use* of components is driven by bundling *different* functionalities in the *same* target system. [9] shows that this goes all the way up to different occupational profiles – component developers are occupied with «design for component» as specialists, component assembler are occupied with «design from component» as generalists.

This also has its analogy in the TRIZ methodology, where «thinking globally» marks the step from the abstract problem to the abstract solution, that, in the best case, is already available as a «technical component», which (after deployment, installation and configuration according to [9]) can be used as solution within a special *real* context, but in most cases still a clear concretization for a complex unique *real world* problem situation is required. So we have also at this level the same distinction as between component manufacturing («design for component») and industrial plants engineering («design from component») in the technical area.

We thus take up the cudgels for a co-evolution of description form and enforcement form in cooperative contexts. Both are not without contradictions, but it can be tried to move articulated contradictions with appropriate transition strategies in the network of systems consciously to such places where they can be resolved.

## 6 Transformation Scenarios and TRIZ

It remains to be understood more precisely how transformation scenarios in the context of TRIZ methodology can be conceptualized. First of all it should be noted that the transformation concept plays a relatively central role in OTSM-TRIZ because to solve a contradictory situation of requirements, which arises in a systemic context, means to identify a suitable transformation of this systemic context into a state in which the contradiction is resolved. The TRIZ methodology helps to find the path of transformation in a systematic way.

This approach differs significantly from the previous approach in two dimensions:

1. It's about the *practical* enforcement dimension of such a transformation.
2. The approach is problem-driven and not analysis-driven.

With the topic «TRIZ and Business» analysis (again) begins to play a greater role by analyzing and systematizing *practical* transition experiences. This brings the TRIZ world closer to transition research in socio-ecological systems, even if still exists a significant difference in the theory/empiricism ratio between the two communities.

[10] is an attempt to gain more theoretical ground on the side of the TRIZ world. First, the object of TRIZ is characterized in the following way: «TRIZ is essentially a distillation of the 'first principles' of problem solving. It was originally developed for complicated technical problem and opportunity situations and, through ARIZ, has been deeply optimized for such roles. Increasingly, however, the world has become dominated by complex, non-technical situations, and in these environments many of the tools, methods and processes of traditional TRIZ become highly inappropriate.» On page 2 Darrell Mann continues «Traditional TRIZ was very much focused on technical problems. And moreover, the large majority of these technical problems turned out to be complicated. And so traditional TRIZ worked. In today's massively inter-connected world, however, it is increasingly rare that we find ourselves able to 'merely' focus on just the technical problem». May be, this describes the problem solving capacities of TRIZ inventive activities in *young* technologies still reasonable. However, this no longer applies to most of today's TRIZ practices, which focus on problem solving (also of engineering type) in *working entrepreneurial contexts* and thus have to consider not only the *solution* of the technical problem but also the *implementation* of this solution in the business context. This means that all systems

are inherently socio-technical systems, because purposes, goals, business strategies and interests come into focus. Such an expansion of the field of consideration from purely engineering to socio-technical issues has also been the subject of GDR inventor schools, which (among other things) solved problems caused by the massive COCOM technology boycotts and corresponding import replacements [6]. Such problems are also today in the centre of important TRIZ applications, in particular in the context of patent circumvention.

However, the question is, whether D. Mann is correct with his characterization of the TRIZ methodology as «first principles of problem solving» or whether these «first principles» – even relevant parts of the theoretical foundations of TRIZ methodology – have to be distributed across *several* levels of abstraction. This question is rarely examined in detail or even mentioned in texts on the theoretical foundation of the TRIZ methodology.

Furthermore, the question arises, whether *problem solving methodologies*, or in other words – institutionalized procedures –, play the same role in the management context as in solving purely engineering problems. In structured contexts the order of the next steel delivery including invoicing and billing is certainly organized in a similar ARIZ-like way as an engineering technical decision process. Hence there's little reason to classify management decisions as in [10] per se as *complicated* or even *complex*. I come back to that question below.

Referencing a «theory of complex adaptive systems» (CAS), the relation to the theoretical background of [1] is evident, even if the theoretical basis in [10] is weak. The title of Darrell Manns reference [11] focuses on «leader's decision making» and not, as [1], on participatory decision-making processes (AM) or transition management (TM). This is also discussed in more detail below.

Let us look at the arguments in [10] in detail. First the example of coil developments shows that even in the world of TRIZ solutions by analogy are bound to concrete parameter ranges whose limits require «disruptive» inventiveness that can only be maintained by transition to other physical and technical principles. Hence we find also in this area the $r$, $K$, $\Omega$ and $\alpha$ phases [7], whereby the analytical strength of TRIZ is particularly useful in the management of transitions, in which polished contexts are to be transcended. TRIZ offers a larger arsenal of abstract trends, patterns and standards in order to enlarge contexts in a targeted manner and to identify transition paths in this larger context.

As already mentioned above in the discussion about [1] and [2] the question stands how universally valid are such trends, patterns and standards. TRIZ theory comes with an universalistic claim in that question, which may have historical root (see [12]) but is practically unjustifiable. A *methodical contextualization* of the TRIZ methodology (when do which methods take effect) is therefore appropriate, and in exactly this direction argues [10]. The model developed there is very simple and relates «complexity» of system and environment on a four-level scale each, which we immediately interpret more precisely as the relationship between system and supersystem. With the «Ashby line» a specific concept of complexity is applied, which we identified in [3] as problematic, as it relies on pure channel capacity and does not consider intelligent compression and decompression techniques.

Nevertheless, the four stages «simple», «complicated», «complex» and «chaotic» can be used to describe the coupling of structuring processes in the system and supersystem. The hint «natural forces act against resilience» [10, Fig .3] relates to the transition from the $r$ to the $K$ phase in [7] and is justified in a similar way: A *young* technology is at first poorly understood and therefore «complex». In the course of further development, not only the description form is becoming more precise, but also the institutionalised procedures. This makes typical application scenarios in typical contexts easier, hence the use of the technology is becoming merely «complicated». With the further development to a *mature* technology this usability is further differentiated and (even if this is not present in [10, Fig. 3]) a «complicated» technology splits into a variety of *different* «simpler» technological solutions for *various more specific application contexts*.

For the «transverse» tendency (horizontal in [10, Fig. 3]) the «2nd law of thermodynamics» is stressed to justify that real-world contextualizations change and thus solutions that were previously suitable do no longer fit. Appropriate counter-strategies [10, Fig. 4] must be used to react to this. The «chaos of the world», which is introduced in [10] with the 2nd law in the considerations, but has its main source in the reductive quality of the description forms, is structured itself and results (among other sources) from transition processes at other places in the «world of systems» with different compatibility with the transistions ongoing in the system itself, as developed more precisely in the typology in [2].

The «horizontal counter-strategies» from [10, Fig. 4] of context splitting and the «vertical strategies» from [10, Fig. 3] of a further simplification and standardization are closely related to each other and can actually only be understood as mutually dependent features of simplification of the description form [10, Fig. 3] and specialisation of the enforcement form [10, Fig. 4]. The «vertical counter strategies» from [10, Fig. 4] correspond to the TRIZ trend 4 of «transition to the macro level» [4] and thus to the stabilisation of the general conditions of the enforcement dimension. Both (diversification in the system and stabilisation of the general conditions) as important resilience strategies also play a role in the past to restrict locally transitions in the world of systems. Diversification means in that regard to make the system more robust against context changes and thus better to withstand conversion processes in the supersystem. Stabilization of the general conditions means the transition to the next level of abstraction, that has the *relationships* between system and supersystem(s) as target of systemic design. Such a perspective remains completely outside of the horizon of [10]. However, in [7] «trend 4» is also understood differently.

## 7 Management of Transformation

M. Rubin (private communication) emphasizes that from the perspective of TRIZ theory it is «essential and obvious» to distinguish between *technical systems* and *socio-technical systems*:

> »When considering a technical system, all existing connections (social, economic, political, marketing, etc.) in the system are hidden, with the exception of objects and links of technical nature. These external (human, cultural) connections can be replaced by additional requirements or restrictions on the technical objects.
>
> When considering systems as socio-technical, together with technical objects and contexts, social ones are taken into account. For example, in the TRIZ analysis of production companies not only the technical system (machines and equipment) is considered, but the factory as a socio-technical object: the system of orders and marketing, the personnel policy, the financial and economic processes, the systems of decision making and

> so on. It is obvious that this fundamentally changes the object of consideration and the instruments of its investigation.

This position fixes in a certain way common TRIZ practices as consulting service: At the end of the investigation of a contradictory requirements situation, a bundle of (technical) solution *proposals* are worked out by the TRIZ-methodically trained consultant as *supplier*, one of them has to be selected by the *client* based on socio-technical criteria and implemented in practice, see in detail also [13]. Of course this raises the question how the institutional boundaries imposed here affect the quality of this decision-making process.

In [11] those processes are described from the «other side» of management processes itself and a different model of a structured approach is developed. Such management *techniques* show the great proximity of these procedures to engineering, but this is in no way be a surprise, since structured approaches do not end leaving a technical area in the strict sense of the term, if one does not take neoliberal fairy tales about the «invisible hand of the market» for serious. The arguments go clearly beyond [10], but also [1] and [2], since [11] does not so much focus on the analytical dimension of the *preparation of a decision*, but on the procedural dimension of *decision making*, and develops a «framework for decision making». The four system classes «simple», «complicated», «complex» and «chaotic» are used to classify decision-making processes mainly according to the quality of the available *basis of decision*.

Rubin's concept of a socio-technical system corresponds to this *system of decision making*, in which besides purely technical arguments, a large number of other mutually exclusive arguments must be weighed. This system of decision making bundles the often contradictory statements and requirements from various other systems, in particular from the technical system in the strict sense of Rubin. But these «other» systems appear both as *supersystems* and also as *components*, as already explained in [13] using a different terminology. They are supersystems in so far as their logic is causally prior to the logic of decision-making, they are components in so far, as the contradictory relationships between these individual logics are to be addressed and equally respected in the process of decision making.

In the sense of our system concept the *system of decision making* (SDM) has to be separated from the various *systems of decision preparation* (SDPs) to achieve the necessary reduction in complexity. The SDM draws on the results the SDPs via their interfaces and has to process the compressed quality of these contradictory information systemically. In such a setting Rubin's distinction between technical and socio-technical system is indeed «essential and obvious». However, the socio-technical SDM does not «combine with the technical objects and contexts also social ones», but those «technical objects and contexts» from the SDPs are present within the SDM alone via their *interfaces*, importing the SDPs as components into the SDM. At this point the distinction between an immersive and a submersive system concept is essential – the supersystem is not characterized by *more relationships*, but *by another direction of complexity reduction* to «the essential». See [3] for more details on this topic.

In [11] methodological advice is given for this purpose, which is solely based on the perception of a degree of inconsistency in the signals from the components. The situation is «simple» if the description forms in the components harmonize to such an extent that only «sense, categorize, respond» is required. The situation is «complicated» if the «experts» from the components can clearly express their contradictory positions and «at least one right answer exists». Dangers are faced in «entrained thinking» of a routine treatment and thus underestimation of such contradictions, the approach to be taken «welcoming novel thoughts and solutions from others» (i.e., shortly: brainstorming) is recommended. The situation is «complex» if the decision has to be filtered out and formulated in the SDM itself, the decision is seen as an «emergent phenomenon», that can only be formulated after a thorough view of the *interactions* between the components, and ist *more* than the sum of the parts.

Therefore [11] can clearly be interpreted in a different way than in [10]. Such an interpretation opens the door to a better understanding of the relationship between the *technical analysis processes* of classical TRIZ and the *business decision processes*, which are necessary for the practical implementation of a solution of the problem under investigation. These two points are present in [11], but not even side by side, since in the SDM the systemic decision-making processes are based solely *on the input* of the SDPs, which should be imported into the SDM via the corresponding interfaces of the neighbouring systems as from *components of the SDM*, and in the best case an iterative decision making model is used, which allows to communicate partial solutions via the same interfaces to the neighbouring systems in order to improve the partial solution within the logics of the SDP and communicate the objections back into the SDM via the interface. The SDM thus takes on an apparent role of a supersystem, but only from an *internal view of the SDM itself*, because such coordination does only work, if the systems in the network of the SDPs are *functionally disposed* to such responses. The coordinating request from the SDM has to meet a function in the neighbouring system that is able to generate a response. For this, within each of the neighbouring systems in the SDP network, the SDM has to be present as a component that provides input in a well-defined format and expects output in an equally well-defined format.

A real supersystem results only from a systemic view on the *relations* between the systems in the SDP network. However, this requires to climb a next level in the epistemic layer architecture, where the topic is not the *concrete* problem solving process in this *concrete* network of SDPs, but the *generalized analysis* of a larger number of such problem solutions. This process of language creation, which is exemplarily demonstrated with the concert example in [5], goes well beyond all the approaches discussed here so far.

## 8 TRIZ and the Development of Technical Systems

How do our notions *system* and *technical system* relate to system notions used in the TRIZ environment? [4] is a good reference for such a comparison, as it summarizes the «development trends of engineering systems» and has the status of an «approved by the MATRIZ textbook». They use the notion of an *engineering system* in difference to other TRIZ literature, especially in Russian language, where usually the term *technical system* is used.

However, neither in [4] nor in the other references precise definitions of the term *technical system* are given. In all sources, reference is made to the *common view*. In a Facebook discussion [14] one could observe the wide range of possible such interpretations. However, even in those considerations, the question raised in our commentary to [10] is not addressed, whether *management techniques* can be covered by an (extended) theory of technical systems or other concepts are required. The retreat to «engineering systems» as in [4] only shifts the problem to the question how far modern management and administrative activities can be subsumed under the notion of *engineering activities*. Concerning the requirements for specific knowledge, theoretical foundations, institutionalised processes and of algorithmic procedures, it is hard to distinguish these activity profiles from classical engineering activities at least in larger companies.

Explicit system theoretical approaches in the TRIZ environment refer to complex roots in Moscow philosophical circles of the 1960s to 1980s, see [13] and the critique of M. Rubin as opponent on this work. Obviously also Altshuller was influenced by this when he developed in 1984 the following list of eight laws of development of technical systems referenced in [4]

1. Law of completeness of parts of a system.
2. Law of «energy conductivity» of a system.
3. Law of harmonization of the rhythms of the system parts.
4. Law of growing ideality.
5. Law of the uneven development of system parts.
6. Law of transition to the upper system.
7. Law of transition from the macro to the micro level.
8. Law of growing substance-field interactions.

Already at this point the descriptions in [4] and [15] differ. Rubin refers to a list of nine laws published by Altshuller in 1977 in Baku and adds a

9. Law of dynamization of rigid technical systems.

Such a rule is also listed as TRIZ principle 15.

[16] seems to be an important reference for the connection between the approaches of «Creativity as an exact science» (Altshuller) and philosophical considerations. In those works the concept of law is strained in order to point out systemic lines of development on different levels of abstraction, and the notion of *technical system* is embedded in the more complex context of the *development of general systems*. The question, whether this are laws or rather trends or even only development patterns, cannot be discussed here.

Both [15] and [16] do not develop a more detailed concept of a general system notion. Goldovsky proposes a hierarchization of the laws in

1. Basic development patterns
2. Methodological patterns of the development of technical systems
3. Laws of the operation of working technical systems
4. Laws of functional transformations of technical systems
5. Laws of structural transformations of technical systems
6. Patterns of transformation of system compositions

where the formulated points rather have a metaphysical character of the contextualization of viewing perspectives. Nevertheless as side effect the concept of a «technical system» is sharpened, in particular by the «methodological patterns» 2.1-2.4.

This hierarchization reflects in a certain way the complexity of system transformations and ranges from

1. Fundamental epistemics of description forms over
2. Requirements for description forms (for modeling) of technical systems,
3. Requirements for the combination of description forms and forms of implementation of technical systems (operating conditions in a given context),
4. Requirements for the solution of contradictions by functional reorganization (with unchanged components),
5. Requirements for the solution of contradictions through structural reorganization (also the components are changed) up to
6. Requirements for systemic reorganisation.

It thus covers a part of the systemic reorganisation requirements, identified in [2]. It remains to be explored, which deeper insights can be gained from these rather metaphysically formulated patterns for coping with *real* transition requirements.

Altshuller himself divides his laws into static (1-3), kinematic (4-6) and dynamic (7-8) ones and postulates the validity of static and kinematic laws for the development even of general systems, while he considers the dynamic laws 7-8 as time- and domain-specific. This reflections are further detailed in [15]. As in [4] the laws are brought into a tree-like causal structure (more precisely: into the structure of a directed acyclic graph). In a second step, the connection to the TRIZ standards is established, which are considered as operational implementations of the respective laws in the TRIZ methodology. From there, a line is drawn to ARIZ and the algorithmization of the methodology.

Both the selection of laws and the exact design of the causal relationships differ between the representation of Lyubomirsky and Litvin in [4, p. 6], Rubin's account of the laws according to Lyubomirsky and Litvin [15, Fig. 1] and his own representation [15, Fig. 2]. Rubin further discusses the connection of these laws to a general systems' theory, for which he proposes 12 laws in 4 blocks. This remains to be analyzed in more detail.

Nevertheless, the question remains open, whether such an approach of *one size fits all* to general development patterns of systems is justified or we need a more differentiated *methodology of application of the TRIZ methodology*.

## 9 Summary and Outlook

The final question remains: How far does a systems theory approach lead in general? We stated at the beginning that there is not *a single* system theoretical approach, but we are confronted with a whole universe of interrelated approaches, which led to the title *Systems Science* of our seminar [3]. Günther Ropohl in [17] further explores this problem and identifies three substantially different approaches

1. the *functional concept* of a system as a «black box»,
2. the *structural concept* of modeling interactions between components and
3. the *hierarchical concept* of a system-environment relationship.

The concept developed here goes with the consideration of the unity of description and enforcement forms a significant step further. The three approaches identified by Ropohl are identified as three reduction dimensions of the description form, which in our system notion act *simultaneously*. Especially the unspecific notions of «environment» and «supersystem» are shaped more precisely: the environment can be introduced in this descriptive approach only again as a system and thus *not* as totality. However, in such an understanding a system can be related to *several* supersystems, which means that the system-supersystem relationship looses its exclusive character among the systemic neighborhood relationships. On the other hand, one has to distinguish between modeling and metamodeling, where the latter is regularly becoming significant when it comes to a systemic version of description forms of *relationships* between systems.

The latter gives rise to a stratification of reality along the levels of conceptualisation of the description forms. This can be considered to be formative for high-tech societies. This description stratification as a specific form of complexity reduction (»fiction» in [5]) finds its equivalent in technical layer architectures such as the OSI 7-layer model.

Systemic considerations identify unity in diversity in the description form, from which diversity has to be restored in the enforcement form. Here people are both subject and object of action. The associated contradictions can in principle be consciously handled, but this contains another stumbling block – self-reference. System theory is overtaxed in this respect and must be embedded in a more general theory of society. With the participatory approach of «adaptive modeling» [1] investigates an important form of such an embedding in a multi-stakeholder context which, however, are weakened again with management approaches such as [11] (and in a broader sense also [4]). System theory remains an important *tool of action* in such a context, if focused on four essential points:

1. Charged with theory,
2. Addressing the level problem of description forms and conceptualization processes,
3. Overcoming the throughput problem: Throughput is essential for the internal conceptualization of the system, the «cooperative world view», as developed in [3] in more detail,
4. Focus on transition and transformation, resilience and sustainability, dynamics of all components and relationships.

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