Men and Their Technical Systems

Hans-Gert Gräbe, Leipzig

July 26, 2020

Published in the Proceedings of the TRIZ Future Conference 2020, p. 399-410. The final publication is available at Springer via `https://dx.doi.org/10.1007/978-3-030-61295-5_30`

Abstract

With the concept of a *technical system* the whole TRIZ theory corpus revolves around a term that is not very precisely defined in the TRIZ literature, but left to a "common sense". In this paper an attempt is made to determine how far a notion of *technical system* takes in this theoretical context and how it can be related to approaches from neighbouring theory corpusses. It turns out that focusing on an artifact dimension of technology, as defined by the term *technical system*, blocks the view on essential *relational phenomena* that are inherent to a *world of technical systems* and a notion of *technical principle* is more suited for the analysis of such relational phenomena.

1 Introduction

The whole is more than the sum of its parts. In [4] I show that it is even much more than this sum, because in the system's *relations* the states of the parts multiply and do not just add up. In that direction the TRIZ Body of Knowledge [8] develops the conceptual foundation of the own theory only half-heartedly. Especially for the question, what is a *technical system*, the "commom sense" is referenced. The diversity of this "common sense" was visible in a Facebook discussion [3] in August 2019. This is of course no foundation for a scientific approach.

In this paper we develop an approximation to the notion *technical system* and ask whether such a term carries on at all in order to analyze the *world of technical systems* more closely. The rarely surprising answer is *no*, because the whole, this world, is more than the sum of its parts. Relational conditions in this world become rather visible in the concept of *technical principle* than in the concept *technical system.* To that extent, the approach in [14] is much better suited to analyze evolution in the world of technical systems as the approach in the official MATRIZ document [9]. The term *principle* is not to be misunderstood here as TRIZ principle, because the unfortunate English and German translation of the Russian origin "приём" is better replaced by "method" or "approach pattern".

For a long version of my arguments with a more detailed explanation (in German) I refer to [5].

2 Laws of Evolution of Technical Systems

Laws of evolution of technical systems exist in different versions and are one of the pillars of the “TRIZ Body of Knowlegde” [8]. They regularly contain a *law of displacement of humans from technical systems.* In this paper I refer to [9] as main reference of the “state of the art”, where influential TRIZ theorists with the authority of MATRIZ compiled a systematization of the current state of debates on such “Trends of Engineering Systems Evolution” (TESE).

The opposite view was formulated in the cybernetics discourse of the 1960s to 1980s [2, p. 10]: “ What is the position of man in the highly complex information-technological system? Our answer to that question was always: Man is the only creative productive force, it must be and remain the *subject* of development. Therefore, the concept of full automation, according to which the human is to be gradually eliminated from the process, misses the point!”

The problems of such a “concept of full automation”, a world of “automatically moving machines” meanwhile triggered an ecological crisis of planetary dimension. The displacement thesis itself is perceived as a direct threat, that can be formulated as thesis itself:

> ***Thesis 1:*** *An (apparent) displacement of humans from technical systems points to an under-complex, existentially dangerous misperception of the technical systems under consideration.*

However, this is no longer a technical problem only. Harrisburg, Chernobyl, Fukushima or the climate change request a further examination of such contradictory positions. The “trends (or laws) of development of technical systems” refer to a *specific* conceptual level of abstraction of descriptions of a world that developes in contradictory forms itself. In particular the “trends” are in contradiction to lines of development extracted on other levels of abstraction. In short, the ambivalent relationship to a “displacement of humans from technical systems” expanded above in thesis and counterthesis is in no way special just for this trend, but applies in a similar way to the other nine trends. TRIZ offers a good methodology to analyze such contradictions if one does not stop at memorizing these trends only.

3 Technology and World Changing Practices

Today operation and use of technical systems is certainly a central element of world-changing human practices. For this purpose planned and coordinated actions based on division of labour is required, because using the benefits of a system requires to operate it. Conversely, it makes little sense to operate a system that is not being used. In computer science this connection is well known as the connection between definition and call of a function – calling a function that has not yet been defined causes a runtime error; the definition of a function that is never called points to a design error.

Closely linked to this distinction between definition and call of a function is the distinction between design time and runtime. Such a distinction is even more important in the real world of technical systems – during design time the cooperative interactions are *planned in principle*, at runtime *the plan is executed.* Hence for technical systems one has to distinguish interpersonally communicated *justified expectations* as *forms of description* and *experienced results* as *forms of performance.*

This is not a simple task as the following example of a concert performance shows. The form of performance, which pleases the listeners, is preceded by the description form, the agreement on the exact interpretation of the work to be performed. This agreement on a *joint plan* is itself a precondition-rich practical process. The requirements result from previous practices – such as the *private procedural skills* of the individual musicians in the mastery of their instruments and the existence of the score as an established form of description of the concert piece to be performed. Since on October 14, 2018 at Leipzig Gewandhaus Alexander Shelley went without this score of Mozart's Piano Concerto KV 491 to the director's podium, we can imagine that this form of description provided at most the raw material basis for director and orchestra in the preceding rehearsals to agree upon a situation-specific special form of description of the performance form. Even more, the opulent gestures of the director towards the orchestra show that during these rehearsals also *language* was generated to transform the results of longer processes of reconciliation into a compact form that meets the time-critical requirements of the tempi of performance. The mere "engineering" dimension was transcended by Gabriela Montero, the soloist of that evening, with her encore: the audience is asked to sing a melody, out of which the virtuoso develops an improvization as a form of performance to which there is no interpersonal communicable description form, beside the sound recordings of that Gewandhaus evening and the reports from the enthusiastic listeners. That also here technical mastery was only a necessary requirement, is beyond question.

The relationship between men and their technical systems is therefore complex and can be grasped only in a dialectical perspective of further development of already existing technical systems, if not to inescapably end up in unfruitful hen-egg debates.

4 Systems and Components

In addition to the dimensions of description and performance, 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 specimens*, even though assembled using standardized components. Also the majority of computer scientist is concerned with the creation of such unique specimens, because the IT systems that control such systems are also unique.

The special features of a technical system result therefore mainly from the *interplay of components*. For example, the production control systems of various BMW plants differ significantly [7]. The plants were built at different times taking into account the respective state of the art and the likewise changing business model of the company. Once such large technical systems are released they can only be modified to a limited extent and are therefore, after the corresponding amortization periods, also consistently decommissioned. Nevertheless, the aspect of reuse also plays a role in such very different technical systems, but is shifted from the immediate level of technical artifacts to higher levels of abstraction.

Hence the *concept of a technical system* rooted in a planning and real-world context has four dimensions

1. as a real-world unique specimen (e.g. as a product or 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
4. as description and operation of the delivery and operating structures of the real-world unique specimens of this system produced according to this template (as production, quality assurance, delivery, operational and maintenance plans).

Point 4 in particular hardly plays a role in the TRIZ context, although neither in the private nor in the business environment technical products are sustainably demanded for which foreseeable inadequate service is offered.

As a basis for such a delimiting system concept, the submersive concept of open systems from the theory of dynamical systems [1] is used, which postulates

1. an outer boundary and functionally determined embedding in a (functioning) environment,
2. an inner demarcation against existing systems (components) that are exploited and
3. a (functioning) external throughput that leads to dynamic internal structure formation as source of the performance of the system.

Technical systems in such a setting are systems whose design is influenced by cooperatively acting people based on division of labour, where *existing* technical systems are normatively characterized at description level by a *specification* of their interfaces and at performance level (at least normatively) by the *guaranteed specification-compliant operation.*

We are clearly within the range of standard TRIZ terminology of a *system of systems* – a technical system consists of components, which in turn are technical systems, whose *functioning* (both in functional and operational sense) is assumed for the currently considered system.

The concept of a technical system thus has a clearly epistemic function of (functional) “reduction to the essential”. To Einstein the recommendation is attributed “to make it as simple as possible but not simpler”. The *law of completeness of a system* expresses exactly this thought, however, not as a *law*, but as an engineering *modeling directive.* The apparent “natural law” of the observed dynamics therefore essentially addresses *reasonable human action.*

In an approach of “reduction to the essential” and “guaranteed specification-compliant operation” human practices are inherently built in, since only in such a context the terms “essential”, “guarantee” and “operation” can be filled with sense in a meaningful way. These essential terms from the socially determined practical relationship of people are deeply rooted in the concept generation processes of descriptions of special technical systems and find their “natural” continuation in the special social settings of a legally constituted societal system.

5 The World of Technical Systems. Basics

In the TRIZ literature such conceptual foundations hardly play a role. Relevant textbooks such as [6] consider the term “technical system” as intuitively given from “industrial practices” [6, p. 2], while other terms such as “process”, “product”, “service”, “resources” and “effects” [6, p. 6–10] are carefully introduced. Even the detailed description of the “evolution of technical systems" in 5 laws and 11 trends [6, sect. 4.8] is based solely on the succinct statement "The existence of technical evolution is a central insight of the TRIZ".

How the concept of a *technical system* can be further sharpened? In [4] we identified "the system concept as descriptional focusing to make real-world phenomena accessible for a description by *reduction to the essentials.*" Such a reduction focuses on the following three dimensions [4, p. 18]:

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

(2) Inner demarcation of the system by combining subareas to *components*, whose functioning is reduced to "behavioural control" via input/output relations.

(3) Reduction of the relations in the system itself to "causally essential" relationships.

Further, it is stated that – similar to the concert example – such a reductive description (explicitly or implicitly) exploits output from prior life:

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

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

(3) An at least vague idea about causalities in the system itself, that precedes the detailed modelling.

The description of planning, design and improvement of technical systems in such an approach is based on the performance of already existing technical systems, which are present both in (2) as components and – from the point of view of a system in the supersystem – in (3) as neighbouring systems. Thus engineering practices are embedded into a *world of technical systems.* From the special descriptive perspective of a system the components or neighbouring systems are given with their *specification* only. Such a *reduction to the essential* appears practically as a shortened way of reasoning about social normality, what I call *fiction* for short. This fiction can and does work in daily language use as long as the social circumstances are in operation, that guarantee the maintenance of the social normality, i.e., as long as the *operation of the corresponding infrastructure* is guaranteed. Hence technical systems are – at least in their performance dimension – *always* socio-technical systems.

6 Engineering Systems and Socio-Economic Evolution

Evolution of engineering systems, as V. Souchkov states in the preface of [9, p. IX], should be considered as "innovative development since – in contrast to nature – craftsmen and engineers make decisions based on logic, previous experience, and knowledge of basic principles rather than chance." The concentration on "craftsmen and engineers" points to narrow practices, from which the systematization in [9] is drawn.

To identify lines of development, in [9] the term *technical system*[1] is embedded between "technology push" and "market pull" as "simple means for understanding the advancement

---

[1] We do not distinguish between the newly introduced term "engineering system" and this old term being in use together with its abbreviation TS in the TRIZ literature for many years.

of man-made systems" [9, p. 1]. The reference to the even more vague term "man-made systems" is explained afterwards in more detail. Innovation as an "improvement of already-existing systems" is supported by the advance of scientific knowledge. This advancement is the source for new systems, products and services to be created. It is driven by a "market pull, the second trigger for innovation" as a shaping selection process, "that stimulates the development of a system by meeting the needs of that system's users". The exact form of this approach, driven not from engineering requirements, but from innovation-entrepreneurial practices, becomes clear in [9, ch. 3]. The foundations of these implicit conceptualizations are located in the framework of the economic system of a capitalist society as supersystem (I add: of western type, since the transferability to more autocratic economic systems as in China or Russia, for example, require additional considerations). In reality, the conceptualization is even more tightly drawn. The analysis of the examples shows that a distinction between industrial plant construction, mechanical engineering and consumer goods production, as common in economic analysis, is not carried out. It prevails the perspective of a larger market oriented company that estimates the product compatibility of technical systems. The unique specimen character of the vast majority of large technical systems and thus the practices of industrial plant construction are not taken into account.

This renders the subject area of technical systems sufficiently clear, whose "evolution" is examined. But what is the aggregation principle for identifying "trends" in such an evolution? Now that we have identified a supersystem, we can use the TRIZ methodology itself to reconstruct the modeling in [9] and analyze its conceptual foundation.

The starting point is the socio-economic (super)system of an industrial mode of production. "The wealth of these societies," Marx begins his analysis of such a socio-economic system in [10], "appears as a 'vast collection of goods', and individual goods are their elementary form. Our investigation therefore begins with the analysis of the goods." We also start with this term as a high level abstraction. As well known Marx' labour value theory abstracted in the concept of *good* from all qualitative characteristics other than the one, to be a product of human labour. Only on such a level of abstraction, special goods become globally exchangeable and constitute a global market as a *relation* – field in TRIZ terminology – between these special commodities, the *exchange value*.

However, that is not what [9] is about, it is about functional qualities of specific product groups such as washing machines or fountain pens. The general competitive relationship between abstract goods is broken down into more specific competitive conditions of individual product groups on individual markets, and in [9] the "market pull" is the main function of the tool "market", which transforms the objects "engineering systems" into "useful products" – I use the TRIZ terminology of [16] on this unusual target. With the marketability of products we identified a first structural unit in the supersystem – special markets at which *special* goods with *specific* functional characteristics – *use value* in Marx's terminology – are competing with each other.

The use value of a good is characterized by a bundle of specific "useful" functionalities, i.e. by the property of a good to be a specific technical component in the sense developed so far. This ensemble of useful features determines the possibilities and limits of the interchangeability of goods in the overall societal technological process. Such borders lead to a stratification of "the market" into special *technology markets* for specific product groups with different MPV (main parameter of value) – according to [9] a central characteristic of such markets.

Such a technology market is less likely determined by the goods traded on it, as by the companies producing these goods. But this shifts the focus from an MPV as an independent characteristic of goods to the *business ability* to *produce* technical artifacts with this MPV in a reasonable price-performance ratio. Hence, on these technology markets meet producers updating their *prior experience* on the contradictions between justified expectations and experienced results in the exchange of their work products. This drives the dynamics of such a technology market.

Hence technical evolution should consider these technological production conditions, too. This is also recognized in [9], because the options for action described in the book refer to the organization of corresponding innovation processes within companies. Hence a *second* supersystem *innovation management* (IM) pops up in our TRIZ analysis – the management structures of companies that are responsible for the innovation process. Again we have to take into account the duality of system template – common social practices of the organization of innovation processes as discussed in [12] – and special real-world systems of innovation in the individual companies. The *main function* of those structures is the organization of innovation processes in close connection with the general business strategy. This process is contradictory by itself, since it has to take into account the *contradictory requirements* of different parts of the company (R&D, sales, finance, controlling, SCM, CRM). The recommendations compiled in [9] are *one* aspect in this complex balancing process. But, compared to the analysis in [12], a methodology between "technology push" and "market pull" remains rather on the level of the 1960s compared to contemporary approaches in management theory. In [12, fig. 3] with "state of the art in science and technology" (ST) next to the "needs of society and marketplace" a *third* supersystem pops up. This third supersystem ST is relevant also for patent grants and the concepts *state of the art* and *level of invention.* Thus we already identified *three* socio-technical supersystems (economy, IM, ST), each with its own terms, structures, components, forms of description and implementation, which, in one way or another, are related to the evolution of technical systems.

The existence of *multiple* supersystems clearly indicates that the term *supersystem* should not be confused with the term *environment.* Supersystems are specific systems with their own language and logic. The relationship supersystem – system is similar to the relationship system – component: they constitute two different perspectives of perception on the "totality of the world" with two different understandings of the *essential* and thus from two different reduction perspectives. From the perspective of the system any supersystem also acts functionally. The description of the system's interface specifies an input and throughput from the supersystem in terms of quantity, quality and structure, required by the system to function at runtime. The supersystem guarantees to fulfill these requirements in the performance dimension. Hence from the system's perspective *a supersystem is nothing more than a special kind of component*, a *neighbouring component.*

7 Normalization and Standardization

One of the main roads of technical development is concerned with normalization and standardization as a prerequisite for *modularization.* Modularization is an important – if not the most important at all – engineering approach that drives the evolution of technical systems. Modular systems are widely used and make it possible to create unique technical real-world specimen in the same way as explained in the concert example. While the *private procedural skills* of the musicians were an essential prerequisite in that example, now the *logic of the business application* appears as "core concern" of the components and the *logic of networking* of the infrastructure as "cross cutting concerns". Both logics are orthogonal to each other, which devaluates the trends 4.2 "of increasing system completeness" and 4.4 "of transition to the supersystem" in [9] in their separate consideration. This suggests the following second thesis:

> ***Thesis 2:*** *A better descriptive understanding of the infrastructure requirements of interacting components (transition to the supersystem) leads to an* attenuation *of the requirements for completeness of the individual components.*

In particular, the arguments in [9] for trend 4.2 to justify the hierarchization into "operating agent" (as core function), "transmission" (support by a working tool), "energy source" (use of forces of nature) and "control system" (use of – nowadays mainly digital – control elements) are affected by these developments, as a visit to a DIY store immediately shows. The machine systems of reputable manufacturers concentrate on provision of energy. Via appropriate APIs (such as velcro, screw or click fasteners on the mechanical level) suitable tools can be joined with the energy machine[2]. Relational effects as normalization and standardization in this *world of technical systems* play a much greater role than the further development of the technical artifacts only.

Standardization also opens up economies of scale for standard components, i.e. for concepts near to the "ideal end results". Economies of scale lead to *decreasing* cost per individual item and thus move the guiding principle of competition from the *better technical* solution to the *cheaper economic* production. So the S-curve does not necessarily end – and probably rarely does – with the decommissioning in stage 4 [9, p. 38], but turns at the height of mature *technical* quality (including normalization and standardization) into the direction of *ubiquity*, in which the *ever-less* economic expenditures for the availability of this "state of the art" take on a leading role in further development.

The trend 4.1 "of increasing (technical) value" thus turns to a trend "of decreasing economic value", or – in economic terms – the market previously driven by demand is turning to a supply-driven market. The same (mature) use value has ever lower exchange value. The value of "ideality" [6, ch. 4.1.1] indeed goes beyond any limits, but as a consequence of an *economic* law. This corresponds to TRIZ Principle 17 of *transition to other dimensions* and can be fixed as a third thesis:

> ***Thesis 3:*** *The (technical) trend 4.1 "of increasing (technical) value" turns in Stage 3 of the S-curve development into an (economic) "trend of decreasing (economic) value".*

This means that in stage 3 the leading function (MPV) of the further development of the production of common tools and standard components turns from the technical driving forces to the economic ones. This process of "commodification" is sufficiently described in [11], hence there is no need to delve into the subject here.

---

[2] Progress in material sciences, in particular with hook and loop fasteners, led to a massive return to *mechanical* coupling principles in contrast to the TRIZ principle 28 of *replacement of mechanical schemes.*

The TRIZ principle 17 of *transition to other dimensions* appears in the above argumentation not as *abstract design pattern*, but as *abstract evolution pattern*, since here it does not operate as a means of active influence of a problem-solving process, but as a description pattern of passively observed real-world developments. In this sense, however, *every other* of the TRIZ principles as well as the TRIZ standards can be formulated as an abstract evolution pattern. Conversely, the trends of evolution can be interpreted as further abstract design patterns that can be used in addition to the "principles" and the "standards". Although this is not new to experienced TRIZ practitioners, see [15], I formulate this observation as another thesis:

> ***Thesis 4:*** *Each of the TRIZ principles and each of TRIZ standards can convincingly be formulated as a "trend of evolution of technical systems" and vice versa.*

The hierarchy of evolution patterns thus gives cause to develop a "hierarchy of TRIZ principles" [18, ch. 3], as proposed by Dietmar Zobel more than 10 years ago, see also [19]. The approach of M. Rubin in [13] to systematize the connections between such hierarchizations remains to be investigated further.

Normalization and standardization heavily influences the evolution in the world of technical systems in an advanced state. We demonstrate these effects in the world of *bolted joints* with machine screws and wood screws.

For the production of machine screws, high precision and coherence of diameter and angle of attack of the threads is required to ensure that they fit with the counterparts. This precision can be reached not only in an industrial production mode, but – for special applications – also with appropriate private tools – e.g., a thread tap. With slotted, crosshead, hexagonal, countersunk head, socket head etc. screws there is a wide range of ready for use solutions for different application scenarios (TRIZ Principle 3 of *local quality*), and corresponding tools: ordinary wrenches, socket wrenches, screwdrivers, Allen keys and so on (once again TRIZ principle 3), both as individual tools and inserts for the cordless screwdriver as an energy machine (TRIZ principle 1 of *decomposition*, TRIZ Standard 3.1 *transition to a bi-system*). Flexible connections[3] (together with the cordless screwdriver TRIZ standard 3.1 *transition to a poly system*) can be used to apply screw connections even in places that are difficult to access and so on. These tools are also used by industrial robots (TRIZ standard 3 *transition to a supersystem* applied twice, because the industrial robots are components in the super-super-system).

The world of wood screws avoids the two-component system (once again TRIZ standard 3.1: bolt and nut), in that the hold in the material itself is sought (trend 4.6 *of increasing degree of trimming* – why this central TRIZ method is neither part of the "principles" nor the "standards"?), either by pre-drilling (TRIZ principle 10 *of previous action*) or by a self-tapping screw (TRIZ principle 25 of the *self-service* or again trend 4.6 of *trimming*). Unfortunately some materials do not offer this grip, thus *anchors* were invented (TRIZ non-trend of *anti-trimming*[4]), a world of technical solutions that are at the heart of every TRIZ practitioner. We didn't touch yet special applications of screw connections as in surgery, where essential parameters of material and reliability are determined by the conditions of the supersystem and lead to very special system solutions.

---

[3] Amazon offers such a 31-piece set of the company Lotex GmbH for 20.99 Euro.

[4] This is a subtle point, since this trend is called "закон развертывания — свертывания" in Russian [8, 2.1.6], but from this bidirectional mode only one direction survived in the English (and German) translation.

I have described this world in so much detail to clarify three aspects:

1) It is a world of technical systems in which principles of problem solving based on TRIZ play an important role.

2) The structuring moment in that world are not the technical systems, but the *technical principles.*

3) The 10 "trends" in a decontextualized fashion are not very helpful to determine your way through highly volatile requirement situations, if you seek for *special* solutions in *special* contextualizations.

In such a world the "evolution of individual technical systems" is of minor interest compared to a global *evolution of technology*, i.e. the "evolution of the world of technical systems" as a whole.

8 Summary

With the concept of a *technical system* the whole TRIZ theoretical body revolves around a term that is not precisely defined in the TRIZ literature, but left to a "common sense". The 40 TRIZ principles, the 76 TRIZ standards and the (in [9]) 10 TRIZ trends of evolution constitute a universe of theoretical reflections of practical inventory experience with a tendency to universalism. Nevertheless overarching generalizations of practical experience and the resulting decontextualization in the TRIZ theoretical body are hardly perceived as a problem in the TRIZ community.

In this paper an attempt was made to determine how far a notion of *technical system* takes in this theoretical context and to relate this with approaches from neighbouring theory corpusses. It turns out that focusing on an artifact dimension of technology, as inherent to the term *technical system*, blocks the view on essential *relational* phenomena in the *world of technical systems.* A notion of *technical principle* as used in [14] is better suited for the analysis of relational phenomena in that world. Hence again: the whole is *more* than the sum of its parts.

References

[1] Bertalanffy Lv (1950) An outline of General System Theory. The British Journal for the Philosophy of Science, vol. I.2, 134–165.

[2] Fuchs-Kittowski K (2000) Knowledge co-production. Processing, distribution and creation of information in creative learning organizations (in German). In: Fuchs-Kittowski et al. (eds.). Organisationsinformatik und Digitale Bibliothek in der Wissenschaft. Jahrbuch Wissenschaftsforschung 2000. Gesellschaft für Wissenschaftsforschung, Berlin. ISBN 3-934682-34-0.

[3] Gräbe H-G (2019) A discussion about TRIZ and system thinking reported in my Open Discovery Blog. `https://wumm-project.github.io/2019-08-07`.

[4] Gräbe H-G (2020) Reader for the 16th Interdisciplinary Discussion *The concept of resilience as an emergent characteristic in open systems* on 7.2.2020 in Leipzig (in German). `http://mint-leipzig.de/2020-02-07/Reader.pdf`.

[5] Gräbe H-G (2020) Men and their technical systems (in German). LIFIS Online 19.05.2020. doi: 10.14625/graebe_20200519.

[6] Koltze K, Souchkov V (2017) Systematic Innovation (in German). Hanser, Munich. Second edition. ISBN 978-3-446-45127-8.

[7] Kropik M (2009) Production control systems in the automobile manufacturing (in German). Springer, Dordrecht. ISBN 978-3-540-88991-5.

[8] Litvin S, Petrov V, Rubin M (2007) TRIZ Body of Knowledge. `https://triz-summit.ru/en/203941`.

[9] Lyubomirskiy A, Litvin S et al. (2018) Trends of Engineering System Evolution. Sulzbach-Rosenberg. ISBN 978-3-00-059846-3.

[10] Marx K (1971) Das Kapital, volume 1. MEW 23. Dietz Verlag, Berlin.

[11] Naetar F (2005) Commodification, law of values and immaterial labour (in German). Grundrisse 14, p. 6–19.

[12] Preez NDD, Louw L, Essmann H (2006) An innovation process model for improving innovation capability. Journal of high technology and management research, vol 17, p. 1–24.

[13] Rubin MS (2019) On the connection between laws of development of general systems and laws of development of technical systems (in Russian). Manuscript, November 2019.

[14] Shpakovsky N (2010) Tree of Technology Evolution. Forum, Moscow. ISBN 978-1-5398-9218-2

[15] Shub L (2006) Caution! The contradiction table (in Russian). `http://metodolog.ru/conference.html`.

[16] Target Invention (2020). TRIZ Trainer. `https://triztrainer.ru`.

[17] VDMA. Machine-building industry in numbers and picture 2019 (in German).

[18] Zobel D, Hartmann R (2016) Pattern of Invention (in German). Second edition. Expert, Renningen. ISBN 978-3-8169-3244-4

[19] Zobel D (2020) Contributions to the further development of TRIZ (in German). LIFIS Online 19.01.2020. doi: 10.14625/zobel_20200119