

Systems and Systemic Development in TRIZ

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Abstract

The concept of systems is central to TRIZ. Problematic technical systems are the main object of investigation in classical TRIZ. Problem solving means to develop "a system as it is" to "a system as required". In his theory of the evolution of technical systems Altshuller identifies development patterns that are useful for such problem-solving and can thus be a guideline for action. In this paper we discuss the interplay of the notion of a resource with such evolution patterns, systems and systemic development with special focus on the operating conditions of such a system.

Systems only become "living systems" when, in addition to functional properties, the operating conditions, i.e. the required throughput of substance, energy and information in a qualitatively and quantitatively determined form, is also ensured. We show that the usual concept of a resource as a "means that can be used to solve a problem" is too unspecific to adequately express these coupling conditions in a "world of technical systems". In that world, most systems are resources for other systems, which means that interface specifications of components are to be used. For practical purposes, this is only possible through standardisation and thus embedding components into *component models* and other higher-level abstract concepts, and their support by technical infrastructures in the form of *component frameworks*. We show that these are the foundations on which a modern component-based mode of production is built.

Keywords: systemic approach, resource, operating conditions, functional and attribute properties, place and content, interfaces, component models.

1 Introduction

TRIZ as a problem-solving methodology unfolds the advantages of its orientation on contradictions especially when it succeeds in delimiting such a contradiction spatio-temporally in an operative zone, to demarcate it there from an "environment" in a systemic way and to analyse it more precisely within such a system. Important tools that are dealt with in [3] such as Functional Analysis, the Analysis of Cause Effect Chains (CECA), Root Conflict Analysis (RCA+), Effects, Feature Transfer or Function Oriented Search (FOS) are based on *functional* properties, in which assuring operating conditions plays a subordinate role.

ARIZ-85C [3, ch. 8], for example, after a first modelling of the "minisystem" in its part 1 "Analysing the Problem" it provides in part 2 "Analysing the Problem Model", among other things, for the determination of substance-field resources. Note 20 *ibid.* states

Substance Field Resources are substances and fields that are already available or are (easily) obtainable according to the conditions of the task.

Specific *qualitative* determinations of such "substances and fields" as resources play almost no role as also in the classification proposed in [3, p. 51-52] according to *value* (free, not expensive, expensive), *quality* (harmful, neutral, useful), *quantity* (unrestricted, sufficient, insufficient) and *readiness for use* (ready, to be modified, to be developed). Such qualitative determinations in the sense of the fulfilment of a *specification* are, however, essential in more complex technical contexts in order to ensure the *operation* of a specific functional property, which is to be provided by a systemic context.

The aim of a systemic modelling of a problematic situation in TRIZ is not only, and not so much, to develop a functionality that solves the problem *potentially*, but to develop the solution upto its practical operational use. For such a practical operation, however, *operating conditions* must exist or be established, which include the use of prestructured resources, which only in few cases "exist or can be easily produced".

In this paper, questions of the relationship between the notion of resources and systemic operating conditions will be analysed in more detail.

2 On the Systemic Approach

The systemic approach is one of the central methodological elements of TRIZ theory. Through a threefold delimitation the horizon of consideration is focussed – by demarcation from the outside against an *environment*, by internal delimitation against *components* and by limiting the *relations* between these components to be considered, see [2] for details.

2.1 Systems and Emergent Functions

Systems are characterised by the fact that they realise *emergent functions* which cannot be reduced to individual parts of the system, but result from the interaction of these partsx [5, p. 17]. For a system considered from the outside as a Black Bo, such a *useful main function* as *main parameter of value* is in the foreground. Usefulness, expediency and purposefulness embed the (technical) system into larger socio-technical contexts and justify the existence of the system itself.

On the respective system level, therefore, the appropriate arrangement and interplay of these *relations* plays a leading role, whereby a distinction is to be made between the dimensions of structural and processual organisation. In the interrelationship of both dimensions the fundamental contradiction of every systemic approach does manifest itself – the contradiction between decomposability and unity in the categorical part-whole relationship. Even if the decomposition of a system into its parts provides important insight into its functioning, the system can only be operated in assembled state. Only in this state the system unfolds its specific functionality. "No part of an aircraft can fly, not even the sum of all parts. Only when united in a system, the aircraft has acquired a new property – flying as a systemic effect." [5, ex. 1.7]

In the TRIZ notion of a *minimal technical system*, a *tool* acts on an *object* (workpiece) to be processed in order to transform it into a *useful product*. The concept of the *ideal system* [3, p. 40] considers the tool as a purely functional property, the effect of which to intentionally change the state of the workpiece to a useful product is achieved without any additional efforts and any wear of the tool. In other words, it is not the tool but the *imaginaton of the*

tool that creates the required action in such an *ideal machine*.

2.2 Systems and Their Operating Conditions

This is, of course, only an ideal picture, since in addition to the structural design of the system also a *throughput* of substance, energy and information through the system is required in a qualitatively and quantitatively determined form. This aspect is somewhat underexposed in TRIZ, as the usefulness of a system is primarily defined in terms of its *useful main function* [3, p. 40], i.e. in its *potential* usefulness.

For the *real* usefulness, the mentioned three types of throughput must be organised, i.e. the system must have *resources* at its disposal for its operation. In the classical understanding of a *complete technical system* [4, 4.2], [11, p. 9] the energy throughput is centered on the tool, the throughput of substance transports the workpieces and the throughput of information is directed to the control of the action. Thus, in any case, the concept of a resource is understood in [3, p. 51] and also [11, p. 7] as "means that can be used to solve a problem."

The understanding of the relationship of action conveyed here is asymmetrical. An active tool has a state-changing effect on a passive workpiece, while retaining its own functionality and – ideally – without undergoing a state change itself. In substance-field models this understanding is replaced by a more symmetrical model of a field-mediated action between two substances. At the same time, in the systemic abstraction, the materiality of the tool is pushed back further and a component concept is prepared as proposed by Szyperki [9] for Component Software. There, *components* are basically conceptualised as *stateless* with all the resulting consequences. In contrast to this *objects* are conceptualised as state-bearing units of instantiation to maintain a certain standardisation of workpieces required for a repeated application of a function within a production process.

Such an approach also corresponds well with the widespread organisation of production processes, where a distinction is made between operating and maintenance mode. In the operating mode, the focus is on the functional properties of the tool, while in the maintenance mode its material properties are focused. As an independent technical system in a narrower sense, only the operating mode is modelled as the target of a "problem solution". The maintenance mode is part of the supersystem, which is concerned with the *reproduction* of the tools as *resources* used in the operating mode. In the (classical) operating mode the focus is on the use of tools and the material throughput of workpieces, which are thereby transformed into useful products, in many cases *technical artefacts*, which are either further processed as semi-finished products in a following technical system or enter into such contexts as tools themselves. In both cases the useful product is a *resource* for further systemic processes.

2.3 Resources

This roughly outlines what must be conveyed by the concept of resources in a systemic context. In [14] Wessner lists a whole variety of concepts of resources proposed by different TRIZ schools. The spectrum ranges from the definition quoted above as "a means that can be used to solve a problem" (Souchkov) to "anything in or around the system that is not being used to its maximum potential" (Mann, Salamatov) to the source of a problem itself: "a problem always arises, if a needed resource is not present" (Orlov).

Let us take a closer look at the definition in [3, p. 51], where a resource is understood as "a

means, a tool to carry out an action or to make a process take place” and equipment, money funds, raw material, energy or even people (human resources) are mentioned as examples of resources. Souchkov also sees Resource Analysis as an essential component of TRIZ with two goals:

- Analysis of the resources that are to be *treated or consumed* in the course of a process,
- and analysis of the resources that can be *used* to carry out the process or to solve the problem,

i.e., he distinguishes resources of the first kind, which undergo state-changing transformations as *workpieces* and resources of the second kind, which are used as tools to *mediate* these state changes.

2.4 Systemic Development and Problem Solving

While the focus of our considerations so far has been on the operating conditions of a *given* technical system, TRIZ is about problem solving and thus it is concerned with the design of viable technical systems in a *systemic development process*. For this purpose the role of Resource Analysis is defined more precisely in [3, p. 51]:

A technical system has different resources at its disposal for the completion of its function. A function can only be completed using suitable resources. Resources are therefore elementary building blocks of a problem solution. The skilful use of resources distinguishes an efficient from an inefficient system.

The question of systemic operating conditions is thus reversed – it is not about what conditions are *required* for the operation of a particular system, but what kind of system under *given* operating conditions promises an efficient problem solution. The focus thus shifts from the operating conditions of an existing system to the question of a systemic development under given conditions. This systemic development can include a complete system genesis, when vague technical solution concepts have to be detailed and developed into a full size practical solution. In most cases, however a working technical system already exists, in which deficiencies have to be overcome, often resulting from changes in operating conditions. Such a conception of the development of a ”system as is” to a ”system as required” is the core of the TRIZ ontology project [10], which aims to further sharpen TRIZ conceptualisations.

In both approaches, a *sustainable* problem solution requires the *sustainable* availability of the necessary resources in the ”environment” to operate the system. Hence in the following we are first interested in the structure of this ”environment” in which these resources are to be found.

3 The World of Technical Systems

The operational demand of a technical system is formulated in the form of *specifications* as requirements to the ”environment”, which must be fulfilled for the *operation* of the system. The ”reduction to the essentials” that characterises the systemic approach is, as already stated above, only a *conditional* mind game that presupposes a sufficiently powerful *environment* as a given, in which the necessary *resources* can be found to fulfil the operating conditions.

However, this environment consists of similarly structured systems, with which the *coupling* of these specifications comes into focus. Technically these specifications are transformed into *interface definitions*, and the specifications are divided into input and output specifications in order to differentiate which resources a system requires for operation and which it produces and makes available to other systems. Those interface definitions are a moment of decomposition of the unity, because it affects *two* systems that are developing separately. In the simplest case the *agreement* on the interface definition takes place in a *supersystem* which covers both systems. Altshuller's development laws of "energetic conductivity" of a system", of "coordination of the rhythms of the parts of a system", of "transition to a supersystem" and to a certain extent also of "transition from the macro-level to the micro-level" [1, p. 72-74] address different aspects of this problem of coordination of interfaces.

3.1 Components, Interfaces, Component Models

Sommerville [8, ch. 6.4] emphasises the importance of such interface specification for the development of software systems that "need to interoperate with other systems that have already been developed and installed in the environment." (ibid) The same perspective is significant when large systems are to be created in a cooperative development process and for this a decomposition into subsystems is required that are to be developed independently of each other [8, ch. 10.2].

Such component-based development scenarios are of growing importance over the last 20 years and developed to an established approach in software engineering, even if no reusable components from third parties are available [8, p. 477]. Systemic development manifests itself as a concurrent process of parallel in time developments and unfolding of subsystems, which is controlled by a socio-technical supersystem of project coordination.

In the V-Modell XT [12], for example, a process model of software development widely used in Germany, the requirements elicitation and system specification are carried out in this supersystem in cooperation between the client and contractor. It concludes with the requirements specification as a detailed (legal) agreement between both sides. This part of the process is similar to part 1 of ARIZ-85C. It is followed by the definition and development of the *architecture* and the *design* of the system including the *component specifications* as a prerequisite and reference for the parallel development of the individual components. At the end of the development process, these pieces are separately tested in *component tests* and based on appropriate *integration scenarios* assembled into the overall system. The behaviour of the whole system with regard to the functional and non-functional requirements is validated in various *system tests*.

Sommerville [8, p. 477] emphasises that this development process in turn requires a more extensive socio-technical infrastructure with

1. *independent components* that can be fully configured via their interfaces,
2. *standards for components* that simplify their integration,
3. a *middleware*, which supports the component integration with software
4. and a *development process* that is designed for component-based software engineering.

Components are thus conceptually integrated into an overarching *component model*, which essentially ensures the technical interoperability of different components beyond concrete interface specifications and thus forms a moment of unity in the diversity of the components.

However, this unity extends not only to the model, but also to the operating conditions of the components (as functional property of the middleware) as well as to their socio-technical development conditions (as a partial formalisation of the development process). This frame constitutes as *component framework* [9, ch. 9] a socio-technical supersystem as an "environment" of components that were created according to the specifications of that component model. At that supersystem level a subdivision of functional properties to be used or to be developed into *core concerns* and *cross cutting concerns* allows for further synergetic effects of a division of labour also on higher levels of abstraction, such as the *CORBA services*, which themselves have component character, but are provided by the CORBA platform as *services* (i.e. as "living components") [9, ch. 13.2].

"Components are for composition" [9, ch. 1.1] is therefore a short definition by Szyperski and those *rules of composition* in turn constitute a diversity of socio-technical development processes corresponding to the diversity of component models, which provide different environments of systemic development processes of concrete components. Szyperski, for his part, analyses in [9] this diversity of compatibilities and incompatibilities of different component models and identifies different levels of abstraction for the reuse of concepts that go beyond the use of prefabricated components. In his 20-year-old book he already emphasises

the growing importance of component deployment, and the relationship between components and services, the distinction of deployable components (or just components) from deployed components (and, where important, the latter again from installed components). Component instances are always the result of instantiating an installed component – even if installed on the fly. Services are different from components in that they require a service provider. [9, p. xvii]

3.2 Functional and Attributive Properties

The explanations show that systemic development processes even within a company working on component-based foundations are interweaved in many ways and cannot be described solely on the level of lines of development of individual technical systems. Szyperski [9] shows clearly that the component approach is an approach of reuse that is not limited to the (possibly modified) abstract reuse of the technical functionality of a problem solution, but always reuses components together with their operating conditions as *services* and thus not detached from their environment.

For this, Shchedrovitsky's distinction between functional and attributive properties in the categorial relation of part and whole, as well as the distinction between the notions of *part* and *element* are essential. This cannot be elaborated here in more detail due to lack of space. I confine myself to the quotation of essential key points in the words of Shchedrovitsky himself.

Elements are what a unity is made up of, so an element is a part inside the whole, which functions inside the unity, without as it were being torn out of it. A simple body, a part, is what we have when everything has been disassembled and is laid out separately. But elements only exist within the structure of *connections*. So an element implies two principally different types of properties: its properties as material, and its functional property derived from connections.

In other words, an element is not a part. A part exists when we mechanically divide something up, so that each part exists on its own as a simple body. An element is what exists in connections within the structure of the whole and functions there. [...]

Functional properties belong to an element to the extent that it belongs to the structure with connections, while other properties belong to the element itself. If I take out this piece of material, it preserves its *attributive properties*. They do not depend on whether I take it out of the system or put it into the system. But functional properties depend on whether or not there are connections. They belong to the element, but they are created by a connection; they are brought to the element by connections. [7, p. 93-94]

3.3 Functional Properties and Ideality

In the TRIZ methodology of the genesis of a system, these functional properties as "usefulness for others" are in the foreground. An engine as itself is not interesting, but only as an engine that drives a vehicle and is therefore "useful". The terms *usefulness* and *harmfulness* play an important role in TRIZ alongside the objectives of profitability and efficiency as socio-cultural guiding principles. With the concepts of *Ideality* and *Ideal Final Result* [3, ch. 4.1] a mental construct of anticipation of the functional properties of a system stands at the beginning of its genesis.

The ideal machine is a solution in which the maximum utility is achieved but the machine itself does not exist. [3, p. 40]

The ideal machine is therefore pure functionality, pure "connection", without any resource-related underpinning. Nonetheless, that fictitious idea, strongly reminiscent of the fairy tale of Cockaigne is central to TRIZ, for it develops a strong orientation towards the intended usefulness and thus has a socio-cultural guiding effect.

3.4 Place and Content

In the further system genesis, this conceptual frame has to be filled with suitable resources [3, ch 4.2]. The systemic concept turns out to be a kind of magnifying glass, under which the combination of the functional properties, filling the "connections" with resources to an almost ideal machine can be observed. To describe this composition process ("components are for composition" [9]) Shchedrovitsky distinguishes the concepts *place* and *content*.

Doing that, we introduce the concepts of 'place' and 'content'. An element is a unity of a place and its content – the unity of a functional place, or a place in the structure, and what fills this place.

A *place* is something that possesses functional properties. If we take away the content, take it out of the structure, the place will remain in the structure (assuming that the structure has a conservative and rigid nature), held there by connections. The place bears the totality of functional properties.

The *content* by contrast is something that has attributive functions. Attributive functions are those that are retained by the content of a place, when this content is

taken out of the given structure. We never know whether these are its properties from another system or not. Now we might take something out as content, but it is in fact tied to another system, which, as it were, extends through this place. [7, p. 94]

The search for resources is constitutive for the process of confinement in the course of the genesis of the system that is to be developed from the pure functionality of the ideal machine. This corresponds to Altshuller's first law of development of "completeness of the parts of a system".

The necessary condition for the viability of a technical system is the existence of the main parts of the system *and* their minimal functionality (i.e. viability – HGG). [1, p. 72]

3.5 Systems of First and of Second Kind

However, the thing viewed with the magnifying glass as a connection of place and content remains a "dead body", because "a living being has no parts" [7, p. 91]. It is of little use to dissect a living frog in order to see how place and content are to be combined, since you cannot study the blood flow in its veins this way. Beyond the connection of place and content an operational process dimension is essential for a living system. In [7, p. 98 ff.] Shchedrovitsky develops that as a *second concept of a system*. For reasons of space, this cannot be explained here in more detail too, except to note that resources are to be understood just as such living systems of second kind. Thus the aspect of liveliness is brought to the place via coupling of content to it. The concept of resources becomes thus much more complicated than in the common TRIZ definitions mentioned at the beginning. The demand to secure the operating conditions does not stop at the boundary of the system.

4 Systemic Development Processes in a Modern Society

We are dealing here with a typical phenomenon of a modern society, in which the electricity comes from the socket and the milk from the shop. The division of labour in such a modern mode of production leads to the emergent phenomenon of social unity and stratification of the reproduction of infrastructural conditions.

In a developed country, one can rely on electricity coming out of the socket and can use it at any time for devices that run on electrical power, provided that the technical standards such as operating voltage and power consumption are adhered to and a suitable plug-socket combination is used. If you connect the plug (place) with the socket (content – here it is important that not only the plug fits into the socket, but that there is also "power in it"), essential operating conditions for the device are fulfilled, it "comes to life" and its functional properties (in the sense of Shchedrovitsky) can be used.

The existence, reliability and robustness (resilience) of such an infrastructure has a significant influence on the way people organise their daily lives. Even in a less developed country where a continuous supply of electrical power is not guaranteed, it is still possible to use electrical devices. However, a coordination effort is required to match the availability of electrical power and the working processes in which the electrical equipment is used. Altshuller's "law

of coordinating the rhythm of the parts of a system” [1, p. 73] is thereby seemingly reversed into its opposite – the more perfect the infrastructure, the less there is a need for coordination with that black box of power supply. Nevertheless the law is not invalidated, because the stable availability of electricity as a resource requires a sophisticated management *inside* the power supply system.

These coordination requirements grow even more markedly in the transition from classical electricity supply systems with clearly defined base loads and unidirectional power distribution to modern systems of decentralised power generation based on ”renewable energies”. The cascade of trends from coordination, controllability and dynamisation [4, p. 6] is becoming increasingly effective and, with smart meter concepts, also reaches the end consumer, who is thus raised to a more comfortable level of rhythmic coordination.

These developments in the electricity supply system, however, are in turn dependent on a digital infrastructure, in which machine-readable descriptions of control information circulate. Evolutionary technological development in the web as one area of technology leads to disruptive changes in this power supply system as another area of technology. The future will show whether those reserves of control potential beyond the (present) limits of the power supply system will be used or whether the *systemic decoupling* associated with an unconditional stable power supply as *anti-trend* to increasing coordination has a socially higher value.

In this way materialises the ”scientific thought as planetary phenomenon” [13]. With the insight into ever more complex interrelationships, a concept of resources as ”anything in or around the system that is not being used to its maximum potential” (Mann, Salamatov, cited in [14]), which focuses on the *exploitation* of resources, becomes increasingly counterproductive and has to be replaced by a concept of resources with socio-culturally institutionalised forms of *resource management* at its center.

The concept of resource exploitation is a characteristic feature of all existing so far forms of a capitalist mode of production. It manifests a fundamental contradiction of socio-cultural development: without such exploitation we would not have reached the current state of technology, but at the same time we undermine our own conditions of existence. My historical optimism says that it is nevertheless precisely these means of increasing conceptual penetration of ever increasingly complex interrelationships by which this trend can be stopped and eventually reversed.

The formulated contradiction is of a global, planetary dimension that cannot be solved by the regional disposition of individual power groups over exploitable resources. The division of the world into spheres of influence thus becomes obsolete insofar as in each of these spheres of influence, the transition to a different form of using resources must be organised to avoid a global environmental collapse of the resources used by mankind in the long run.

5 Conclusion

We have shown that in our modern ”world of technical systems” the question of resources to be used in a systemic problem-solving context cannot be reduced to ”substances and fields that are already available or are (easily) obtainable according to the conditions of the task”, but has to cover also resources that are both offered and required in a highly pre-structured form. These pre-structures are secured by standards and supported in that ”world of technical systems” by ”living” technical systems of second kind in the sense of Shchedrovitsky. This is

also true for "substances and fields", because the operation of an electrical device requires not only the availability of an electrical field as such, but a field with precisely defined operating properties.

Trends of increasing coordination, controllability and dynamisation [4] refer not only to system-internal development lines, but also to the coordination *between* systems which are operated by independent third parties. Qualifying the infrastructural framework, for example, of the power supply system as "supersystem" does not take into account the relations of *mutual interdependency* in such a modern industrial mode of production.

Socialism or Barbarism? Rosa Luxemburg [6] raised this question and did warn in 1916, during the First World War, of further wars and catastrophes. At a distance of 100 years and in view of new barbarism of the successor of the leading socialist state, the question arises whether the alternative should be formulated differently. The barbarism is linked to the destruction of important reproductive contexts and shows the vulnerability of modern social structures. However, the technical means available today also allow asymmetrical responses. 2022 is not 1916.

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