General Scenario of Technological Evolution: System's Evolution beyond its Original S-curve

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Introduction

Timely invention of next generations of various products is a crucial issue in achieving sustaining growth by an enterprise. Numerous working teams, focus groups, etc. are dedicated to the task; however, the results are not adequate. In fact, there is a clear indication that corporate research and development have failed in delivering innovative products on continuous bases[1] in spite of various attempts to facilitate the process using special creative techniques like brainstorming and its numerous modifications. At most, a group or extraordinary talented individuals can come with some useful ideas; however the process does not guarantee that these ideas are the best possible or exhaustive (the latter is especially important for obtaining an adequate protection of developed intellectual property in the form of innovations and/or know-how).

In the mid-1970s Genrich Altshuller, the originator of the Theory of Inventive Problem Solving (TRIZ) suggested a systematic approach and a technology for invention of next generations of various technological systems (TRIZ forecasting) based on newly introduced Patterns of Evolution[2]. Typically, the approach would include application of

[1] William L. Miller and Langdon Morris, *Fourth Generation R&D*. John Wiley & Sons, Inc., 1999.
[2] Altshuller, Genrich. *Creativity as an Exact Science*. Translated by Anthony Williams. Gordon and Breach Science Publishers, 1984.

selected patterns and/or trends to an existing product, system or situation, or mapping it on selected lines to identify possible next steps in evolution. One of the most important elements of the approach became S-curve analysis that is, defining the position of the system on its S-curve (birth, fast growth, maturity and decline) and offering further steps depending on this position. During the next three decades, this approach and knowledge base has been substantially expanded involving revealing and documenting additional patterns and numerous Lines of Evolution[3]. The process of this expansion, however, has been still generating various problems and uncertainties that needed resolution.

For example, the actual practice of utilization of multiple patterns/lines has revealed that different patterns, lines or trends can prompt:

- The same next step
- Different next steps that are compatible
- Contradictory steps

Other problems were associated with complexity of the nature of the S-curve evolution, in particular how many S-curves can one system have; are these curves sequential or develop in parallel; what are the relationship between the system's main S-curve and the S-curves related to its sub-systems, etc.

In the mid-1990s utilization of Patterns, Lines and trends of evolution for invention and invention based prediction of future generations of technological systems became a foundation for Directed Evolution™ process – a systematic procedure for strategically evolving future generations of technological systems via development of practically exhausted set of potential scenarios of evolution.[4] Each scenario in this process is a combination of potential steps that are compatible or can become compatible after resolution of certain contradictions.

Invention of next generation has different requirements to the utilization of patterns /lines of evolution than an enhancement within existing system. As usual, next generation means transition to a new S-curve.

The interaction with the overall level of technology has a different level of importance for systems evolving within an existing S-curve and the ones that have exhausted the resources of the existing paradigm. In the first case, this interaction could be as follows:

- Transfer of conventional knowledge that is, implementing solutions known in other areas and applicable to the given area.
- Implementation of new technologies that can improve the existing system within its recent paradigm.

In the case of the system maturity, the impact of the overall level of technology is even more important as it usually becomes the only way the system can avoid complete death.

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[3] *TRIZ in Progress.* Ideation International Inc, 1999.
[4] Zlotin, Boris and Alla Zusman. Directed Evolution: Philosophy, Theory and Practice Directed Evolution. Ideation International, 2001.

Working on the underlined theory for scenarios development we has got an understanding that although obviously for different situations (systems) different possible scenarios exist, however, at least one general scenario has been unveiled that could be applied practically every time[5]. In this article we would like to elaborate on this issue.

Definitions and assumptions

To describe the system evolution beyond its original S-curve, we will need to make certain assumptions and definitions.

System, its name, main function and principle of operation

We define a system as a product, process, technology, etc. designed to perform a certain ***main or primary function*** to satisfy a particular ***need/purpose***. A ***system name*** could be very general including many variations (aircraft) or more specific (an airplane). Accordingly, the system main function can be more or less general/specific. The system's main function is realized through a certain ***principle of operation***. Typically, the same function can be realized in more than one way; in this case for each principle of operation we might have a different system (an airplane, a helicopter and a hang-glider have different principle of operations while the main function – flying – is the same).

System's lifecycle, generations and evolutionary resources

As it was mentioned earlier, the typical system's ***lifecycle*** can be illustrated by its S-curve. We assume that the birth of a new system (S-curve) unveils (creates) new ***evolutionary resources*** that allow the system evolve while gradually consuming these resources. When the original resources of the concept are exhausted, the system enters the maturity stage followed by decline.

We also assume that we are dealing with the same lifecycle of an evolving system as long as its main function remains the same. Often, the principle of operation stays the same too, especially if it is reflected in the system's name (for example, reflector (mirror) telescope). As it was mentioned earlier, the system's lifecycle description can be extended and enriched if we select more general name (the life cycle of an aircraft system has more events (generations) than of an airplane).

We define a ***system's generation*** as a portion of a system's lifecycle represented by its own (partial) S-curve. Obviously, a system's lifecycle can include a number of generations.

Typical scenario steps

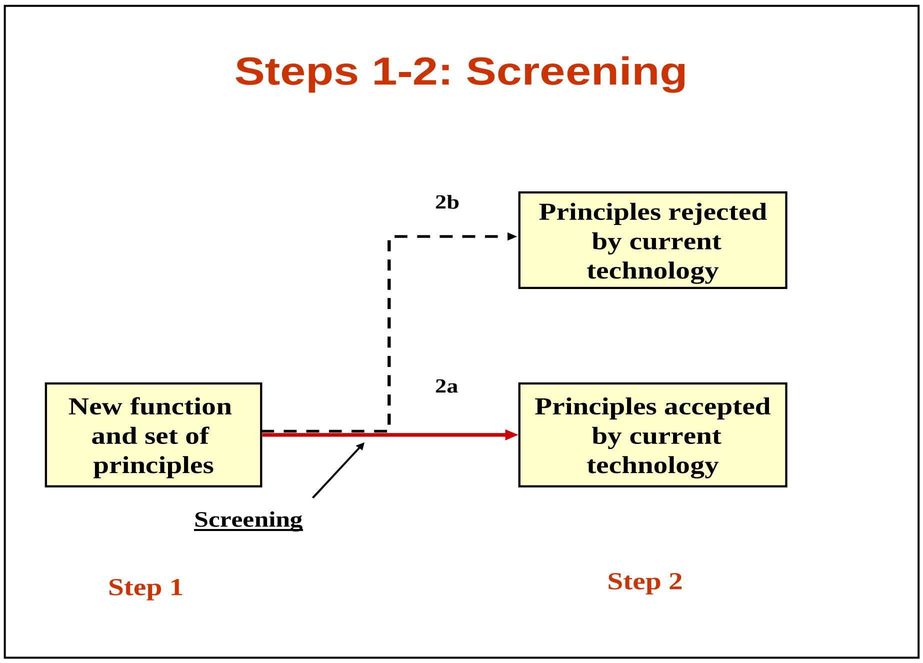
[5] *TRIZ in Progress.* Ideation International Inc, 1999.

Step 1 – The beginning

From the history of evolution of numerous man-made systems, it starts from many trials involving exploration of different principles of operations. For example, what kind of propulsion should be utilized for an airplane: energy of muscles, steam engine, combustion engine or even jet engine[6]? This period can be rather long, especially in cases when inventors are trying to realize a long time dream (like flying). During this period, the different concepts encounter a screening imposed by the overall level of technology.

Step 2 – Screening

In the screening process, certain principles are accepted while others are rejected (see the picture below). For example, although the history has proved that jet engines represented a more advanced option, the overall level of technology was not able to support it in the beginning of the last century given the condition of material science, physics and chemistry, and enormous technological challenges that have to be overcome. As a result, combustion engine won this step.

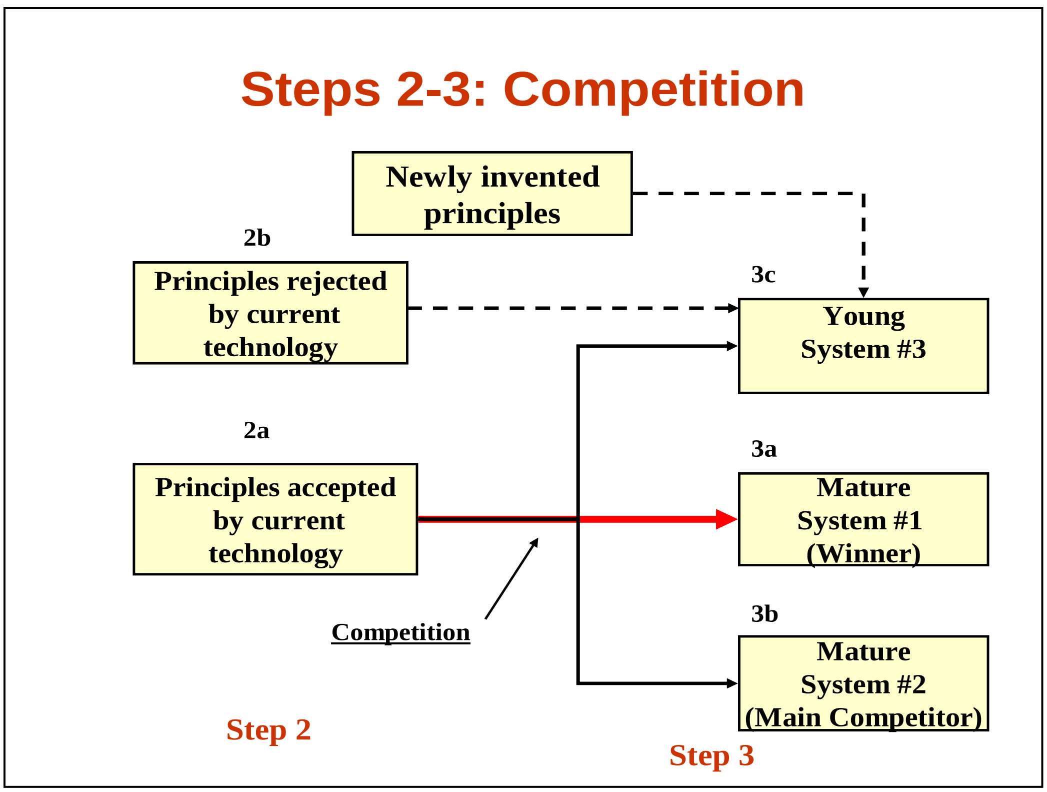


Step 3 – Competition

[6] It is known that the first airplane with jet engine took off in 1910, only seven years later than Wright brother's flight in 1903.

During this step, principles that have been accepted by the current level of technology enter competition. Eventually, this competition results in a limited number of mature systems[7] one of which could be a recognized winner (#1); at least one main competitor (mature system #2) and at least one young system (#3). The reason that the number of players is limited is simple – the overall amount of resources the society can allocate for the system is limited, and once a few systems have proved their best potential, investors and efforts are focused on them, leaving very little left to the outsiders. The reason why young system(s) is still there is every time rather unique and yet common in general: strong dedication of certain individuals that believe in the technology, occasional financial support, etc[8].

In some cases, the young system is one of those that squeezed itself through the screening, in others it could be one based on a newly invented principle (see the picture below).

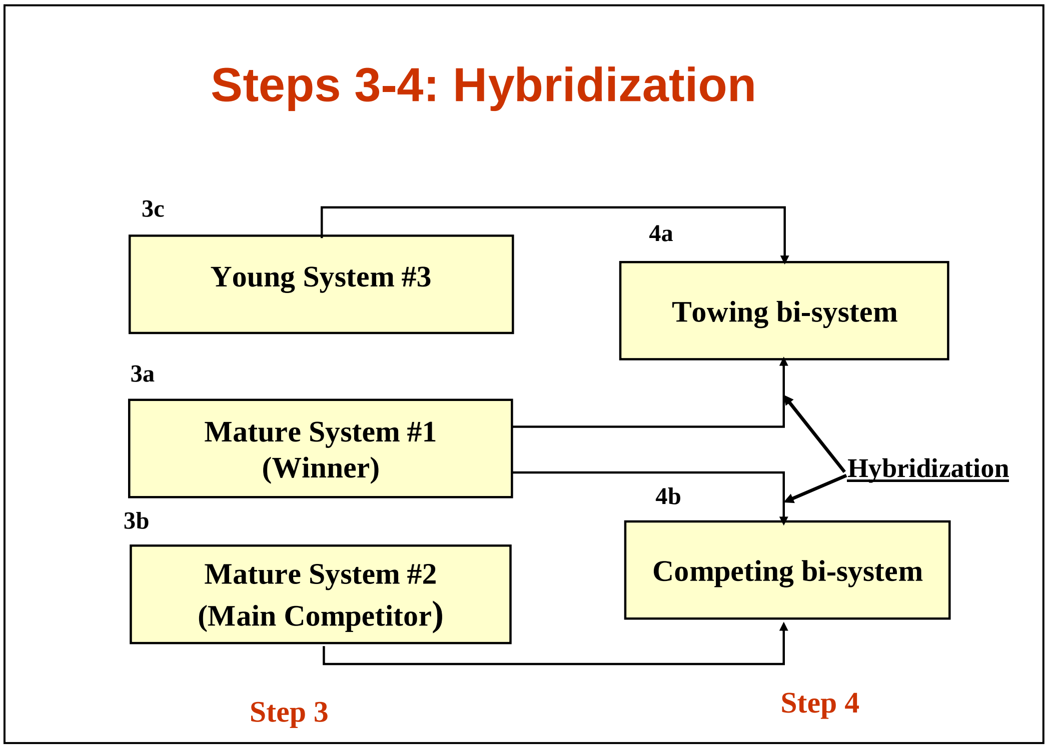


Step 4 – Hybridization

Once the main players (including mature and young systems) have been established and demonstrated their main advantages and disadvantages, it is time for invention of various

[7] In this case, we are talking about systems that have reached their maturity as a stage of the S-curve.
[8] In recent days, certain countries or societies can allocate certain resources for these particular purposes (incubators for new non-trivial ideas and approaches, seed money, etc.), however, the chances to attract serious attention are not there before the accepted paradigm does not become obviously obsolete.

combinations that later was named as hybridization process. Similar to biological hybridization, this process involves combining of certain useful features of different systems in the most effective way[9]. To date, a number of different types of combinations have been revealed[10]; however, from the evolutionary point of view, the most interesting are creation of Towing and Competing bi-systems (see the picture below).



Towing bi-system

Creation of a towing bi-system is a rather common evolutionary step and represents a very effective way of hybridization of:

- A ***mature technology*** that cannot evolve any further because of exhaustion of evolutionary resources of the original concept.
- A ***new (often disruptive) technology*** (young system) that has a high potential yet still is neither efficient nor reliable enough to replace the old one.

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[9] At first, combining of competing systems in technological evolution has been described by Boris Zlotin in his 1983 paper in the Russian Journal of Inventors and Innovators. In the late 1980s Vladimir Gerasimov and Simon Litvin developed the first step-by-step procedure for this integration (*Why technology favors plurality?* Journal of TRIZ v.1, no 1, 1990). Later, Vladimir Gerasimov teamed with Valery Prushinskiy and Gafur Zainiev, Ph.D. and the latter has suggested the new name “hybridization” emphasizing the similarity with biological evolutionary step. The procedure has been also advanced at this time (TRIZ in Progress, Ideation International, 1999).

[10] The most comprehensive list of possibilities see in Ideation software Innovation WorkBench (IWB)® system.

In these situations, the mature technology "tows" the new one, providing the following advantages:

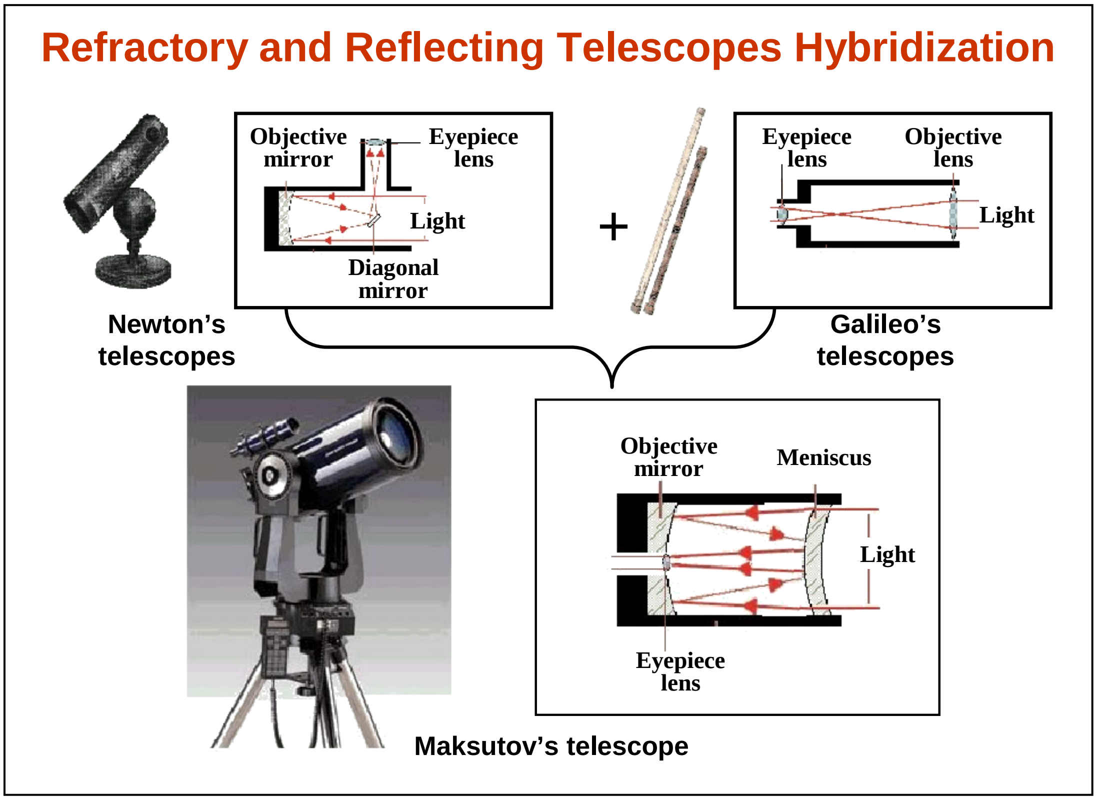
- The mature system is allowed for longer life as the young system provides with new features/qualities.
- More time for the traditional industry to adopt a new paradigm.
- The young system is allowed to be utilized as it is backed up by the mature one.

For example, early steamships were inefficient and incapable of long distance travel. Ships that combined steam and sails were built to get the advantages of both[11]. In a similar manner, early jet engines were used on aircraft as boosters for piston engines as they weren't efficient enough to take care of the whole flight including taking off and landing.

Competing bi-system

As it was mentioned earlier, the reason there exist different systems providing the same main function via utilization of different principles of operation is that they practically always have different (often opposite) advantages and disadvantages. In the case of competing bi-systems, we are dealing with ***two mature systems*** that are close to exhaustion of their original evolutionary resources. The concept can be illustrated using evolution of telescopes invented by Galileo (refractor or lens telescope, 1609) and Newton (reflector or mirror telescope, 1668). In 1941, after about 300 years of fierce competition, Maksutov invented a lescope that provided the high resolution at a fraction of the cost of the original telescopes (see illustrations below).

[11] At the earlier stage of the boats evolution, boats were using both oars and sails.

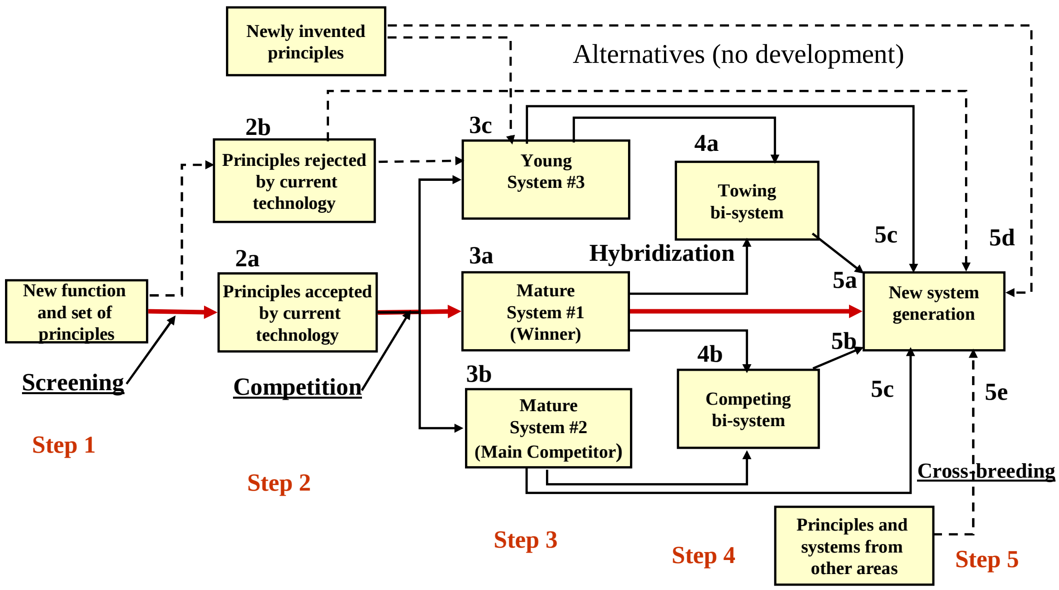


an be repeated many times: the first hybrids can be further hybridized with one of the original systems, with one another and/or with their successors.

Step 5 – Creating an inventory of candidates for the next generation of the system

Now it is time to consider all candidates for the next generation. From the picture below one can see that there are a number of possibilities.

Steps 1- 5: Unveiling and Exploring All Potential Directions



In particular, the next generation system might be one of the following categories:

- 5a: Towing bi-system resulting from hybridization of a mature old system (3a) with a system, which is still in the beginning of its evolutionary cycle (3c).
- 5b: Competing bi-system resulting from hybridization of a mature old system (3a) with the one developed in parallel, which is at the same stage of development (3b).
- 5c: Mature system # 2 or a young system
- 5d: Alternative principles, earlier rejected or newly invented, integrated into the old mature system for continued advancement.
- 5e: Principles and systems implemented in other areas integrated into the old mature system (Cross-breeding).

Conclusion

The picture above shows evolution of a system in the context of overall technology evolution and allows for systematic exploration of possibilities. Like any unveiled and documented pattern or line of evolution, the scenario described above has predicting power. For example, attempts to rush with a brand new technology before trying it in a hybrid could be a very expansive mistake that could be easily avoided if R&D personnel are properly educated in the nature of technological evolution. For us, for instance, it was quite obvious that attempts to build a commercially available completely electric car wouldn't be immediately successful because hybrids should go first.

The picture above also demonstrates how important is to do the historical analysis of the system evolution. Because typically the early steps of evolution contain information about unsuccessful (and often forgotten) attempts that later can serve as evolutionary resources, this information becomes an extremely valuable condition to ensure exhaustiveness of the variants to consider before making decision on direction for the next generation of the given system.

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