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Chapter 3

Trends of Engineering Systems Evolution and Agricultural Technology

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Abstract

The new products are certainly decisive for achieving the business success of companies involved in the design and production of agricultural technology. Reducing the risk in the development and introduction of new technical products is the goal of analyzing the evolution of technical products. Effective innovation engineering procedures in the conceptual design phase do not use deductive methods such as brainstorming, but use more advanced methods with varying degrees of detail to describe the identified trends in the evolution of technology. In the case of this chapter, we will focus on so-called trends of engineering systems evolution. They describe natural transitions of the engineering system from one state to another, and are generally valid for all engineering disciplines. These are guides to the directions of development and their individual development phases, which should keep track of innovated products (through innovation, improvements and combinations of successful systems and technologies) so that users' needs are met more. Trends are generally the basis of modern technological forecasting and strategic planning. Unlike conventional forecasting methods, knowledge of trends can more accurately predict the problems associated with the introduction of new technologies and thus increases the probability of success of the chosen solution.

Keywords: evolution, trend, engineering, system, agriculture, technology

1. Introduction

Within the traditional approach to analyzing trends in the development of technical products, various procedures and methods [1–8] are used. We can divide these traditional techniques into five groups: techniques based on experience, assessment, and intuition; market research techniques; time series techniques; techniques using regression analysis; and other quantitative techniques. Information input for the majority of these methods is usually a subjective

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feeling and intuition, which of these methods makes a real mix of science and art. It is clear that the methods of technology forecasting should more include objective rules of the development of technical systems.

Because different technical systems overcome the "same types" of problems, their general development over time is "typical." These typical trends of engineering system evolution have been identified on the basis of a broad analysis of patent databases and historical trends in technology development [9–13]. Trends occupy a special place in the innovation science and engineering field, as they offer a view of the technical system from a variety of time perspectives—from the past through the present to the far future. They have a great potential for problem solving because they describe what happened in the past to successful technology and because they are leading the developer to what is likely to happen in the future for these technical systems. Therefore, prediction or, at least, a non-deductive view of what is likely to benefit the direction of development in a specific industry from the point of view of the system and its components can be used. In connection with the term "trend," it is also important to point out the terms "law" and "pattern." According to [13], the trend is describing general evolution directions of system components and can be graphically presented as a vector. "Laws of technical system evolution" only give general description of the links between phenomena. "Evolution pattern" is the specification of some trend (route map) [13]. Trends are of a statistical nature and cannot be understood as being filled in the last letter [14]. Of course there are frequent exceptions and deviations in which trends will not apply, for example, in a surprising technological discovery, fashion trends not based on logic or in situations where users' needs are not in line with technological developments.

Evolutionary trends represent, by analogy, external manifestations of "natural selection" in the world of technology, because even technical systems are struggling to use as well as biological species for survival sites. Systems that have survived their "birth" (idea, invention) and better met the demands of human society (i.e. high performance, low costs, and little impact on the environment) have won the evolutionary competition. As an example from agriculture, we can mention the hand scythe tool (**Figure 1**). In a traditional shape, scythe is perfectly adapted to carry forces from the human body and arms for effective grass mowing or grain mowing. However, the evolution of this agriculture tool has lasted more than 2000 years, and its development, for example, from the shape and material viewpoint still continues [15, 16].

Formally, trends or patterns of engineering system evolution are systemized guides and a description of the "winning" transitions from one development phase to the next that allowed the technical solutions to occupy and maintain a leading position in the market. Knowledge of trends and patterns can also be used in the so-called evolutionary analysis, which aims to obtain information on general directions for improvement of an innovative object or to formulate the correct tasks for the transition from one development phase to the other in the direction of the subline of evolution.

According to [10], trends of engineering system evolution are 11, and together they form a hierarchical system. From the two main trends (the S-curve development and the trend of increasing ideality), the other trends are derived (**Figure 2**).

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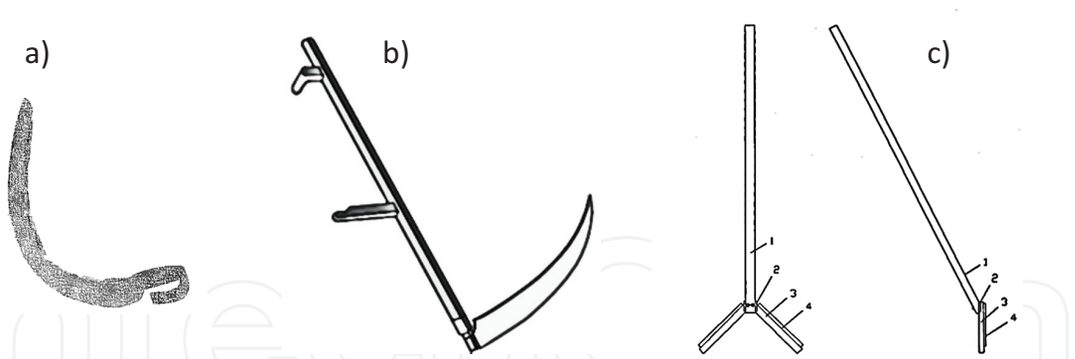


Figure 1. Hand scythe tool shape evolution ((a) ancient Egyptian sickle, (b) traditional European hand scythe, (c) newly patented Asian bidirectional scythe [16]).

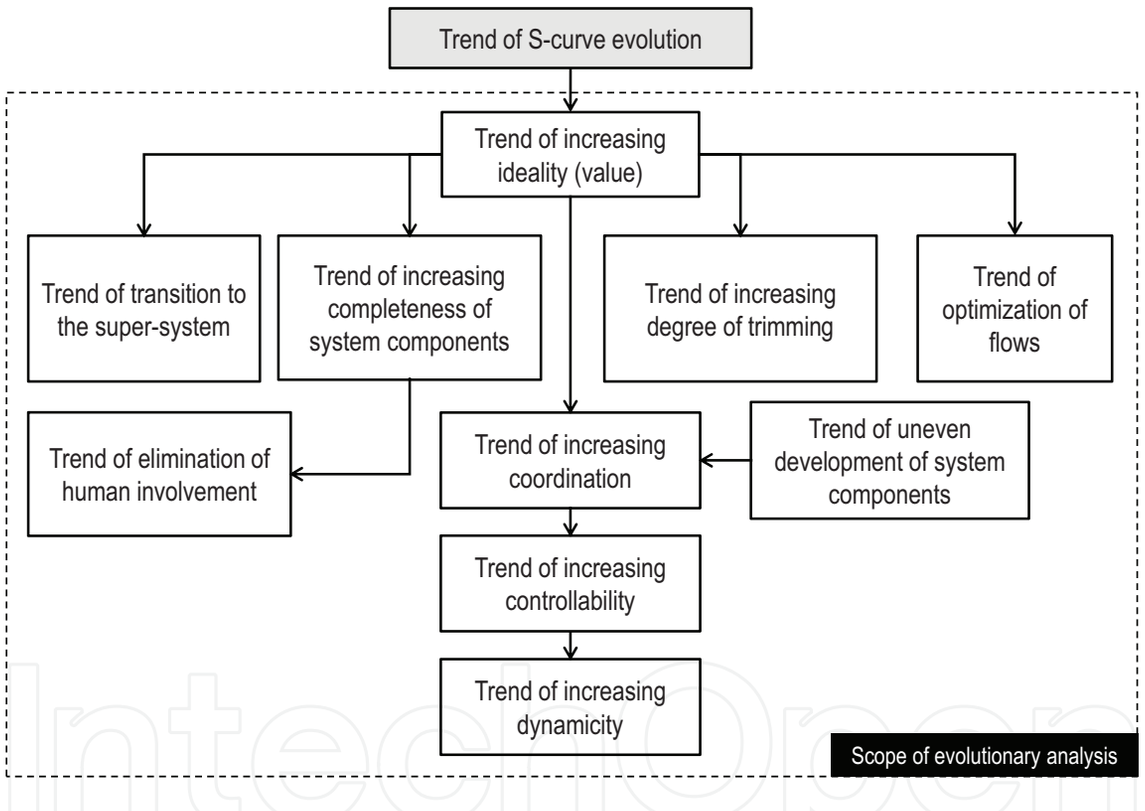


Figure 2. Hierarchical system of trends of engineering system evolution (adapted from [10]).

In the next section of this chapter, we will briefly focus on selected trends of engineering system evolution [10] from the agriculture technology viewpoint.

2. Following trends in the agriculture technology field (brief analysis)

Trends of engineering system evolution (TESE) can be a powerful tool for technology forecasting, innovation strategy development, and technical product innovation [17]. Related

evolutionary analysis is an analytical-synthetic method, the aim of which is to look for the directions of innovation of the analyzed technical systems. This analysis usually takes place after identifying the shortcomings of current technical systems and technologies. In the analysis we are gradually considering the application of selected trends relevant to the analyzed field of technology. If, for example, there are no human-technology relations in the analyzed case, it is possible to exclude from the evolutionary analysis the trend of elimination of human involvement. The result of the evolutionary analysis is to assess the currently achieved stage of development of the given technical (sub)system and formulate recommendations and tasks for further innovation in the direction of successive phases or steps of a specific trend of engineering system evolution [10].

S-curve refers the shape of the logistic function used to illustrate the diffusion of innovations in the technology life cycle [18]. Since the trend of S-curve evolution mainly reflects the result of technological innovations expressed in the context of changes in the main parameters of technical systems, this trend is not considered in evolutionary analysis, but it is used at the very beginning of the innovation process at the stage of setting innovation targets and benchmarking studies (**Figure 2**).

Trend of increasing ideality (value) is the driving force for engineering system innovation along the S-curve, as well as driving force for diffusions of innovations. Altshuller [9] and [10, 13, 19] formulated ideality similarly to value as:

$$I(V)=\Sigma F/\Sigma C \tag{1}$$

where I (V) is engineering system ideality or value, ΣF is total functional capabilities or performance of useful function(s), and ΣC is total costs of performing function(s). System ideality can be increased by following principal approaches (see **Figure 3**):

1. $\Sigma F\uparrow; \Sigma C\approx \text{const} \Rightarrow I(V)\uparrow$
2. $\Sigma F\uparrow\uparrow; \Sigma C\uparrow \Rightarrow I(V)\uparrow$
3. $\Sigma F\uparrow; \Sigma C\downarrow \Rightarrow I(V)\uparrow$
4. $\Sigma F\approx \text{const}; \Sigma C\downarrow \Rightarrow I(V)\uparrow$
5. $\Sigma F\downarrow; \Sigma C\downarrow\downarrow \Rightarrow I(V)\uparrow$

According to this trend, engineering systems increase their ideality, e.g. if their weight, dimensions, and energy consumption are decreasing (ideally close to zero) but their ability to perform functions is not diminished. In other words in the course of engineering system evolution, the ideality increases due to the increasing relation of system's functional potentialities and total cost of its creation and operation [10].

The limit ideal system is when cost is zero and/or functionality is infinite. Popularly speaking, "the technical system does not exist, but its main function are further provided." Functions in this case are the interactions of subject and objects, and they are described in the specific form as "subject – action (verb) – object." Agriculture is distinguished from other fields of

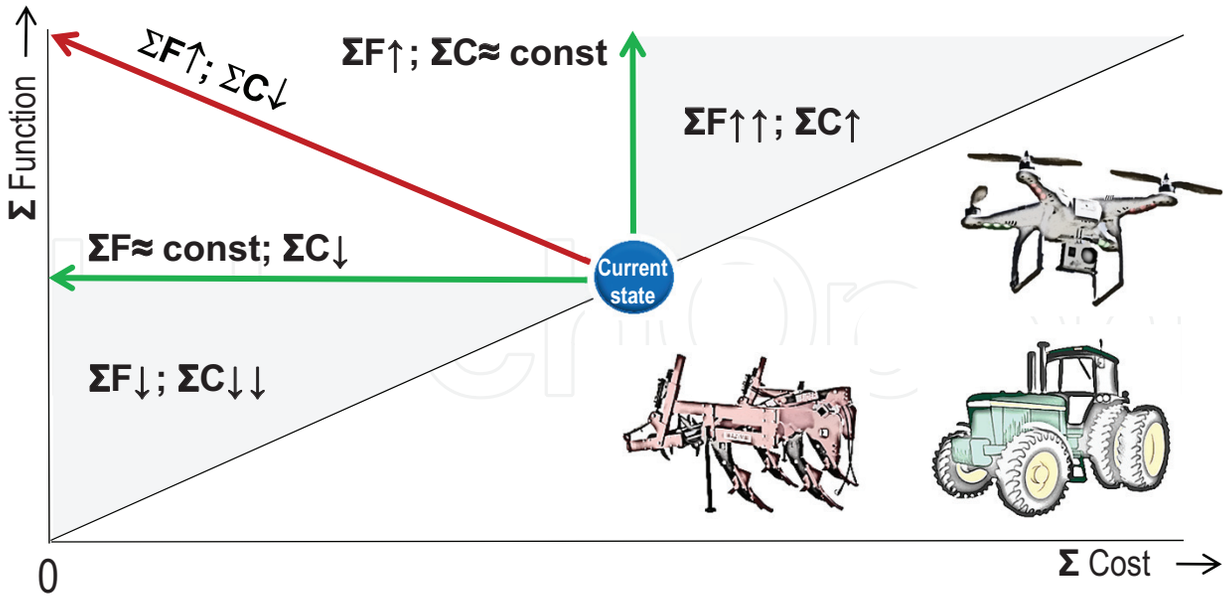


Figure 3. Possibilities to follow the trend of increasing ideality (value).

technology because it provides useful and harmful functions by system components as soil or animals. An example of this trend following toward an ideal technical system in the field of agriculture is shown in **Figure 4**.

The trend of increasing degree of trimming is that the number of components decreases during the development and innovation of the technical systems without compromising the functionality of the system (**Figure 5**). It is clear that one of the ways to reduce costs is to remove several components from the system. If we moreover succeed in preserving (or even increasing) the functional potential of the system, its idealness will naturally increase.

Maintaining functionality is ensured by following three trimming rules focused on redistributing useful functions of eliminated components to the remaining components or by transferring these useful functions to supersystem elements:

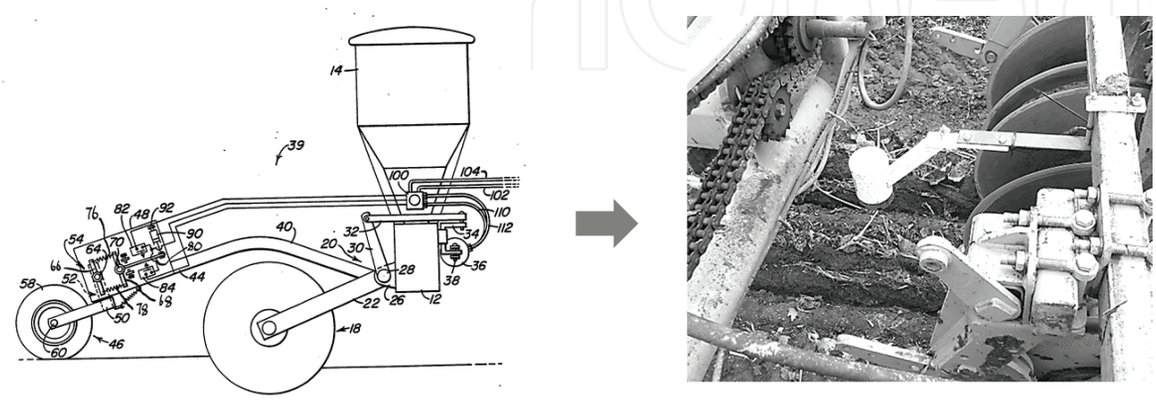


Figure 4. Mechanical depth control by wheels or rollers and)non-contact depth control by sonar sensors (controller) with lower weight and smaller dimensions [20, 21].

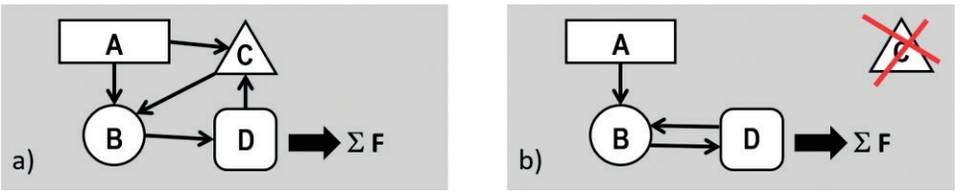


Figure 5. Trimming implies removal one or more components from original system (a – original system, b – improved system after trimming).

- trimming rule #1: function carrier (subject) can be trimmed if we remove the object of its useful function;
- trimming rule #2: function carrier (subject) can be trimmed if the object of function performs the useful function itself; and
- trimming rule #3: function carrier (subject) can be trimmed if another component performs its useful function.

In **Figure 6,** the trend of a higher degree of trimming can be illustrated by the example of hydroponic or aeroponic crop cultivation [22, 23]. By removing (trimming) the soil, many soilborne pests and diseases can be eliminated. This innovation also eliminates problems with nutrient availability and deficiencies caused by soil. As a result plants are healthier and grow much faster than plants in soil. Following the trend of a higher degree of trimming in a form of soil trimming enables to create and operate complex high-tech platforms for hydroponic or aeroponic crop growing in a closed and controlled environment. For example, a hydroponic growth system may be integrated into a programmable system providing for the growth of plants (**Figure 7**). An upper section of a system may include a lighting system able to vary lighting characteristics such as the intensity or spectral content of light provided to the plants and atmospheric systems to control the temperature, flow, or humidity of air around the plants that are mounted on an actuated platform. A control system may execute a program to control the available systems including the actuated above-plant platform to programmably control the height or heights of the systems above plants [24]. Such hydroponic or aeroponic high-tech systems also include advanced sensor systems. For example, the first sensor system measures one or more characteristics of a nutrient solution; a second sensor system measures one or more characteristics of an environment of a plant and a network device including a communication interface to the first sensor system and a communication interface to the second sensor system. The network device may be configured to transmit measurements from the sensor systems through a wireless network to a remote device or database in the Agriculture 4.0 direction [25].

One of the strongest and most frequently applied trends is the **trend of transition to the supersystem.** This trend reflects the fact that in the course of its evolution, the systems exhaust their internal resources and subsequently the original system integrates with other (even alternative or competing) systems and continues its development in the so-called supersystem (freely understood the supersystem as a "surround" of the system). As a rule, the functions

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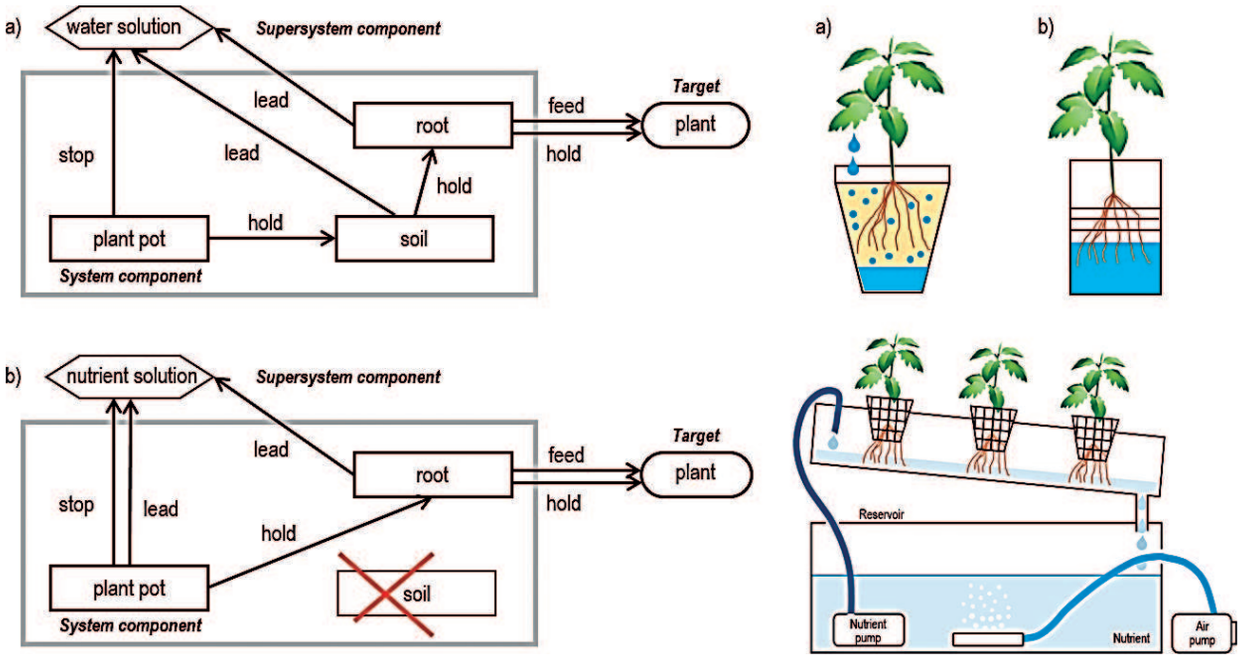


Figure 6. Functional model of traditional plant growing (a) and trimming model for hydroponic plant growing (b).

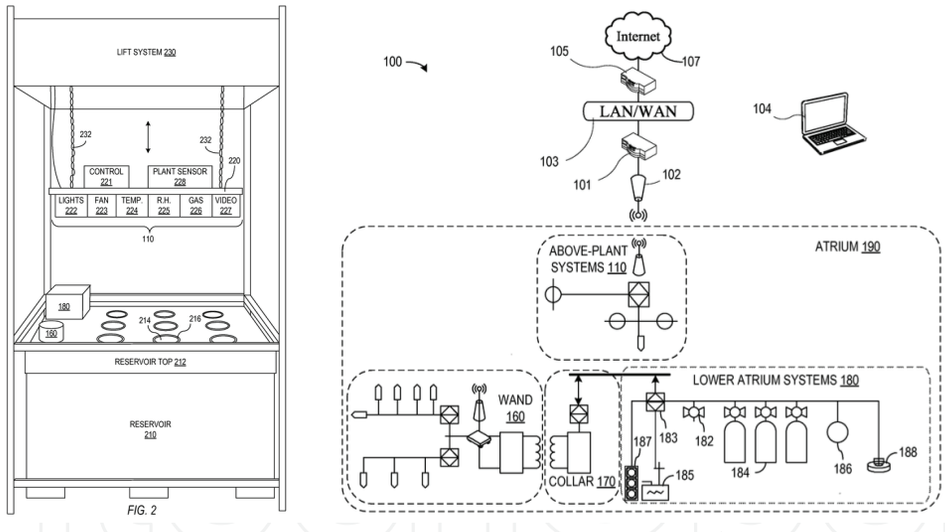


Figure 7. Hydroponic system with actuated above-plant platform [24].

and quality of the old system are passed on to the new one, i.e., the new system does not originate without the old system. The trend has four subtrends [10]:

- subtrend #1: the parameters of the integrating system are increasingly different from the original system parameters.
- subtrend #2: the main functions of integrating system are increasingly different from the original system main functions.

- subtrend #3: the level of integration between the original system and the integrating system is deepening.
- subtrend #4: the number of systems that integrate with the original system is increasing.

Example of the subtrend #1 in the agriculture field is illustrated in **Figure 8** by multipurpose agricultural unmanned helicopter as an agent of intelligent agriculture technology. The transition from one development phase (vehicle) to the next stage (rotorcraft) is triggered by the rapid development of modern agriculture, where traditional spraying or transporting methods no longer meet current requirements of precision agriculture.

The **trend of increasing efficiency of substance, energy, and information flows** is that the evolution of technical systems that contain substances, energy, and information flows is progressing toward increasing the efficiency of the use of these flows [10]. Under normal circumstances, any flow transformation (transformation of a substance from one state into another, changes in energy types, changes in the content of information, etc.) is accompanied by losses, deceleration, and delay. In fulfilling this evolutionary trend, the stream with several transformations of energy turns into a homogeneous flow. Ideally, there should be no transformation at all, and all components of the flows should be at once in the form that is needed for their utilization [10]. This trend is illustrated by example of the straddle electric tractor (**Figure 9**) showing transition of the agricultural ground transport from combustion engines with several energy transformations to electric propulsion and battery pack that will fully power even large tractors for agriculture.

The **trend of increasing coordination** is reflected in the evolution of technical systems by gradually coordinating the "behavior" of the system components and consequently coordinating the "behavior" of the supersystem [10]. Coordination is also understood as the choice of one parameter with respect to the value of another parameter. This "driving" parameter value can be preselected (e.g., when manufacturing the agricultural machine) or in the process of its operation (e.g., during harvesting or weed-destroying processes). For example, when developing the outer shape of a system, the shape of the developed system must be coordinated with the shape, properties, and movement of the objects that interact with the system (an example of this trend being the standardization of the dimensions of the interconnected parts or the ergonomic agricultural tool handle solution). From this trend viewpoint, we can observe different trend mechanisms—coordination in shape, coordination in rhythm, coordination of materials, coordination of action (**Figure 10**), coordination of parameter, self-coordination, etc., [10].

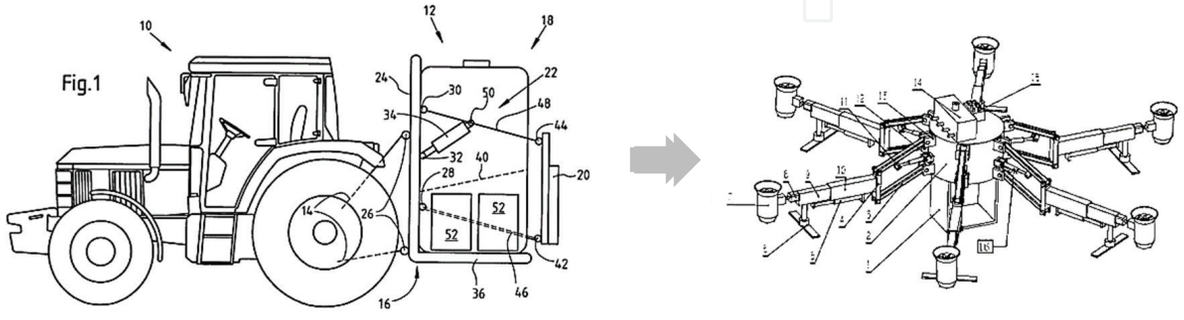


Figure 8. The transition to an integrated system with better parameters than the parameters of the original engineering system [26, 27].

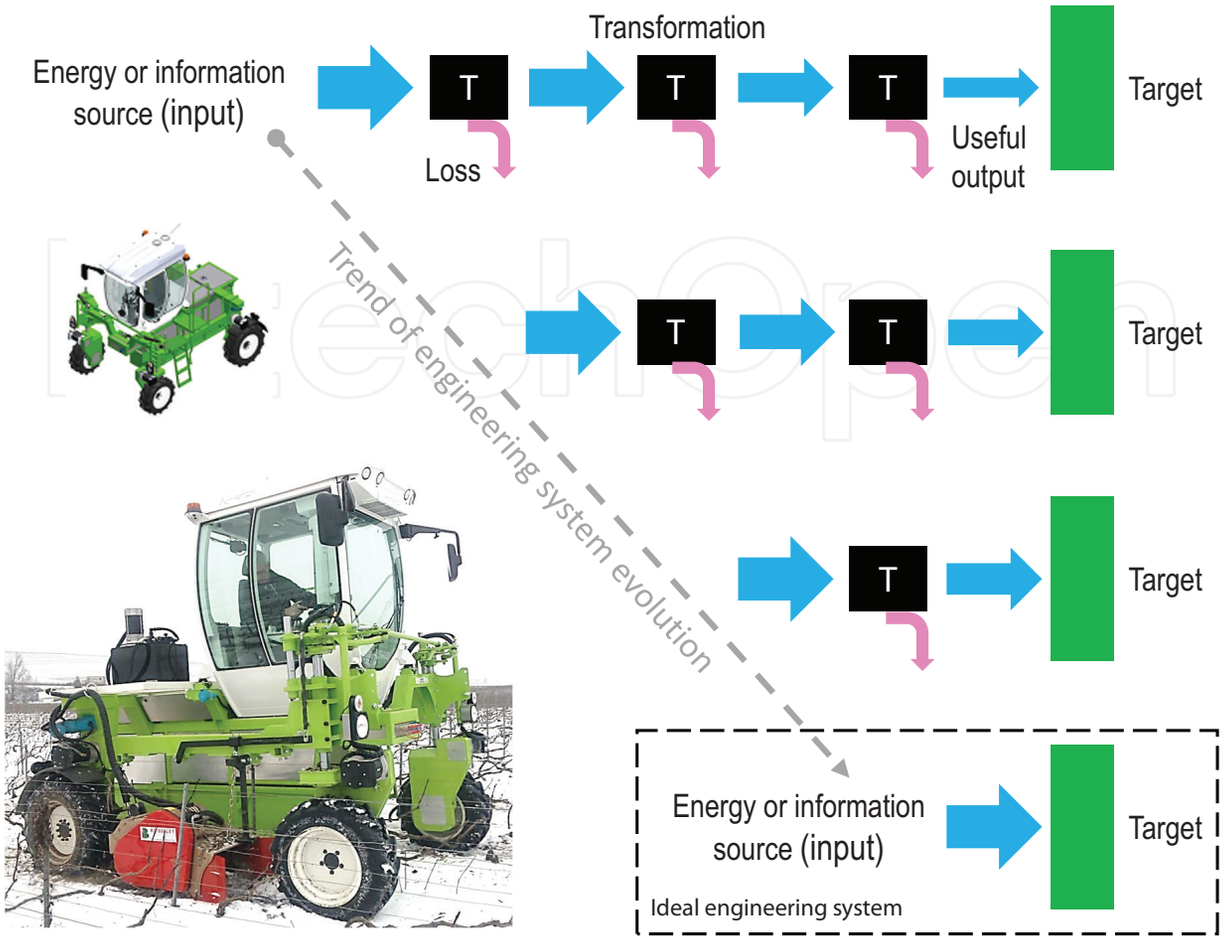


Figure 9. Enhancement of conductivity of useful flows through reduction in the number of flow transformations (one of the possible fulfillments of the trend in the form of electric straddle tractor, T4E [28]).

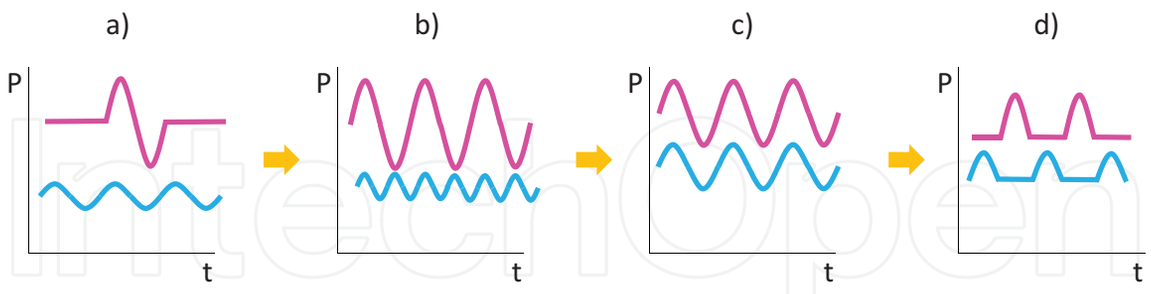


Figure 10. Trend of increasing coordination of engineering systems ((a) incoordinated actions, (b) partly coordinated actions, (c) coordinated actions, (d) interval actions).

The trend of increasing coordination in the form of coordinated actions can be illustrated by example of a system for speed-based coordinated control of agricultural vehicles when on-the-go unloading is utilized (i.e., the harvester is in motion) (**Figure 11a**). This control system [29] includes a controller communicatively coupled to the first transceiver, wherein the controller automatically controls the speed of the haul agricultural vehicle by determining a desired position and a desired speed of the haul vehicle based at least in part on the first determined position and the first determined velocity of the target vehicle,

instructing an automated speed control system to establish the ground speed of the haul vehicle to reach the target position and instructing the automated speed control system to control the ground speed of the haul vehicle to maintain the target position, including during turning of the target and haul vehicles. The transceivers may broadcast and receive radio waves within a frequency range of about 1 GHz to about 10 GHz. In addition, the first and second transceivers may utilize any suitable communication protocol, such as a standard protocol (e.g., Wi-Fi, Bluetooth, etc.) or a proprietary protocol [29]. Another example of this trend may be wireless networking of agricultural machines in a collaborative agricultural process (**Figure 11b**) [30].

The **trend of increasing dynamicity** lies in the fact that during the development of the engineering system (components), the flexibility, dynamism, or adaptability increases. The development of engineering systems in the direction of this trend proceeds from an initial rigid structure with unchanging parameters to a more flexible and variable structure with more degrees of freedom, with adjustable parameters and a working mode adapted to changes in the external environment. For example, engineering system that has rigid components is poorly adapted to operating conditions. For this reason, the evolution of rigid components becomes more flexible and dynamic. First, a single joint, and then multiple joints, are inserted into the solid monolith. Moving from joints to flexible fabrics, the system gains flexibility and adaptability. Fluids or gases are even more adaptable. Finally, the system is converted to some of the physical fields that have the best controllability (**Figure 12**) [10].

The trend of increasing dynamicity in the agriculture technology field can be illustrated by innovations realized within precision agriculture (PA) that is based on observing, measuring, and responding to crops or soil variability. Proactive decisions are made with the support of

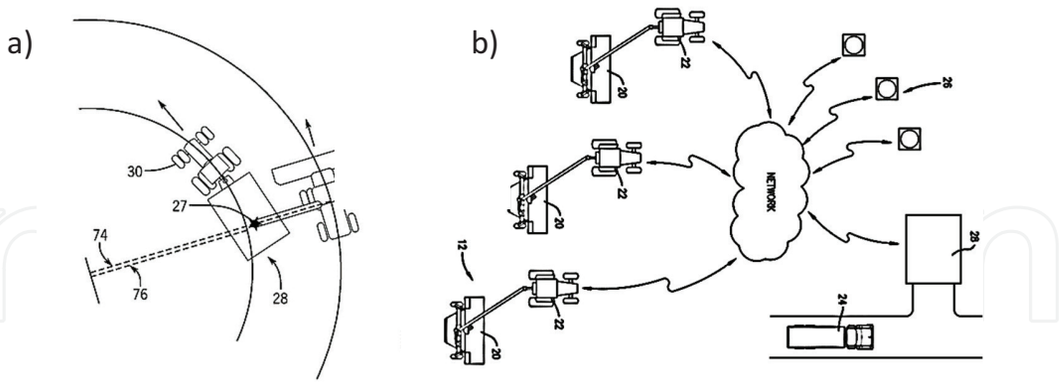


Figure 11. Automatic coordination of the agricultural vehicles speed (a) and synchronization of agricultural vehicles with the help of wireless networking (b) [29, 30].

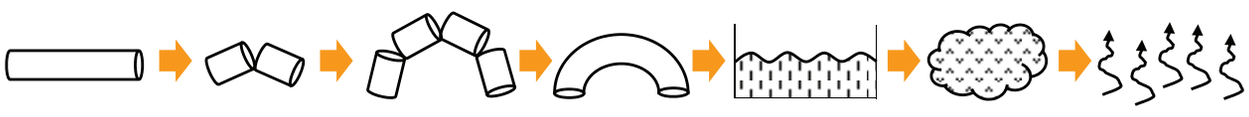


Figure 12. Trend of increasing dynamicity of engineering system component.

Agriculture 4.0 tools and techniques as sensor systems, robotics, computational techniques, positioning systems, or big data to manage variability and control site-specific applications. Progress in this trend direction can be documented on the development of harvesting robot grippers whose design deviated from hard-to-handle robot hands with rigid fingers to design with flexible fingers or cushioned finger design (**Figure 13**).

The **trend of elimination of human involvement** in engineering system trend lies in the fact that during evolution, the number of functions performed in the system by human is reduced [10]. This trend is particularly relevant for systems where standard subsystems such as the workpiece, transmission, power source, and control system are omitted and initially do not exist (**Figure 14**). This is a special case of the **trend of increasing completeness** of engineering systems, because a man is often an element on which it is usually easiest to transfer the functions, which yet cannot be performed by the system.

Fulfilling this trend in agricultural technology can be documented on the concept of an autonomous cabless tractor [35] or on the unmanaged robotic platform for performing multiple functions in agricultural systems [36] (**Figure 15**).

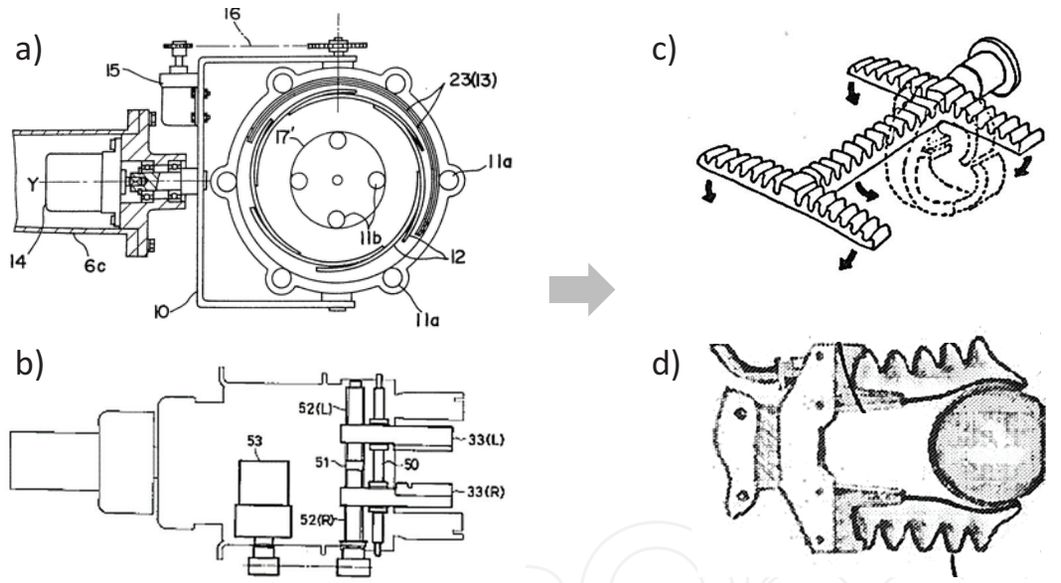


Figure 13. Dynamicity increasing of harvesting robot grippers ((a) [31], (b) [32], (c) [33], and (d) [34]).

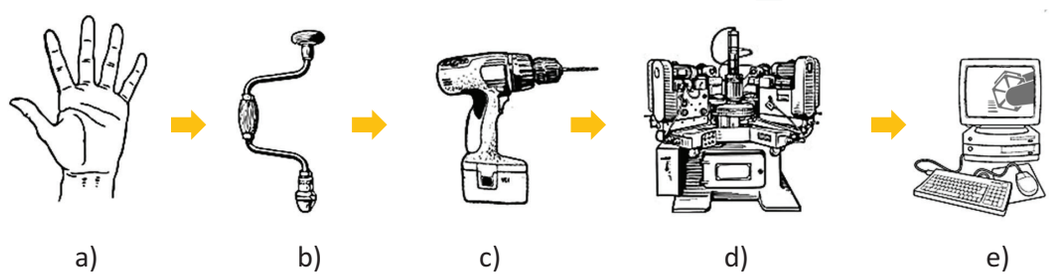


Figure 14. Trend of elimination of human involvement in engineering systems (human roles: (a) man alone, (b) tool, (c) energy and drive, (d) control and supervision, (e) only decision-making).

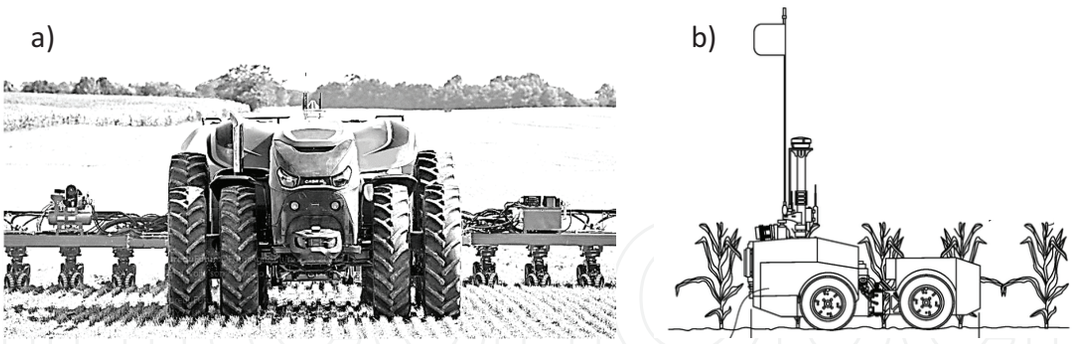


Figure 15. Trend of elimination of human involvement in engineering systems: concept of autonomous tractor (a) and robotic platform (b) [35, 36].

3. Technology forecasting using systematic creativity methods

The paradigm of innovative companies is the transition to new, market-successful, types of products. However, market success must be thoughtfully directed, i.e., it is necessary to read, respectively, to forecast the future. All traditional forecasting techniques (market research techniques, Delphi method, time series analysis, regression analysis, etc.) are aimed at finding key issues for shareholders, investors, and business owners before launching development work and putting new technical products on the market "What is the business potential of the new product?" Input data are typically industry and market information, experience, subjective feelings, and intuitions, which make these methods a mix of science, randomness, and art. In order to solve the prediction task more objectively, it is possible to use two creative approaches extending traditional technological forecasting

- TRIZ technological forecasting—what changes should be made to move our product or process to a further developmental position in the specific trend of the technical systems?
- Directed evolution (**Figure 16**)—which development scenario should be selected from the identified set of scenarios to make the product, service, or process successful?

Since directed evolution (DE) can be considered more complex, let's take a brief look at its principles. The coauthors of directed evolution method B. Zlotin and A. Zusman [8] continued in the classical TRIZ forecasting (which alone is not enough to manage the development and evolution of products) and added evolutionary sources to Altsuller's innovation principles. Directed evolution is then based on the following five theoretical backgrounds (postulates) for creating scenarios of future development:

1. Application of system development models (lines). Most manmade technical systems follow rather predefined models than they would be a result of random phenomena. This means that a strategy based on the proactive approach of the eight identified development models and the resulting development lines can maximize profits and reduce the cost of technical or other innovation.

2. Market-oriented direction of development. Most manmade technical systems follow tor customer satisfaction. It means that they evolve in the direction of increasing ideality.
3. Consumption of resources for system development. The development of the system is based on the consumption of internal resources, sources from surrounding systems and the surrounding area. In the initial stages of the S-curve, easily available sources are utilized. These sources are later replaced by complex or hidden sources. New types of products will usually appear when new sources are discovered (structure or material).
4. Priority of long-term forecasts. Prior to improving system parameters and resources, long-term general development of the technology is preferred, including the inclusion of new generations and fundamental discoveries.
5. Application of system development alternatives. The engineering system always has more than one possible path to the next stage of development (according to various sources). The most profitable new system is usually the one that is launched first, which attracts most of the financial and human resources [8].

The basis of the DE is the diagnosis that follows the initial formulation of the problem and the collection of adequate data. The aim of this diagnosis is to identify the possible directions of evolution (development scenarios) of the given engineering system and to formulate all the problems and tasks that must be accomplished in order to fulfill this direction of evolution (development). Performing DE diagnosis means, for example:

- Compare historical data with trends and development lines.
- Identify missing and future development steps that are understood as innovative opportunities.
- Identify bad development trends.
- Identify unsolved contradictions.
- Extrapolate development directions (lines) for a given technical system [8].

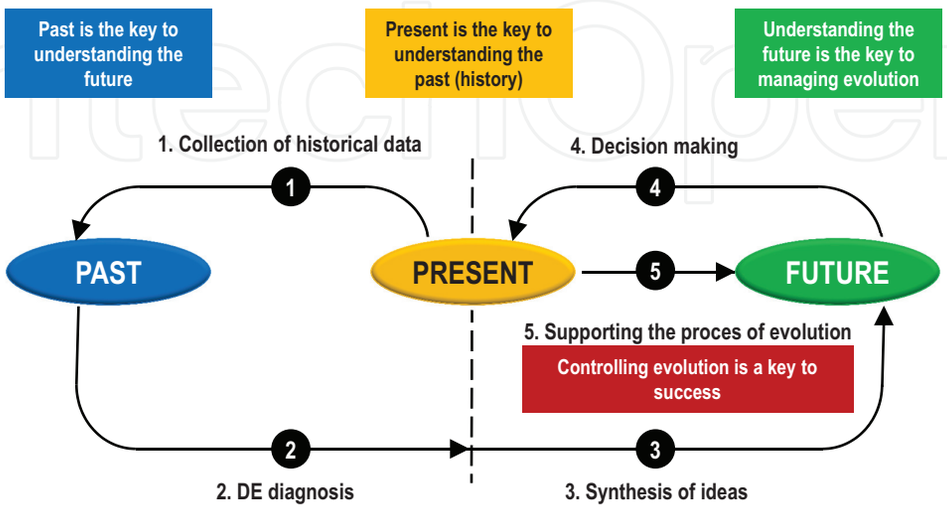


Figure 16. General schema of directed evolution [8].

The result of the DE is the concepts of innovative products that correspond to both identified scenarios (trends) of the development of a given technical (or social [8]) system and concepts based on the resolution of exposed contradictions. Prognoses created using systematic creativity methods can provide management and engineers with important and more reliable input into the strategic planning process because they are based on objective patterns in the development of technical systems. These predictions can be used not only to better understand future threats and present opportunities but also to actively influence the future as a contrast to passive and reactive problem solving, because the best way to predict the future is to invent it.

4. Conclusion

Trends of engineering system evolution (TESE) can be a powerful tool for agricultural technology innovation and forecasting. The goal of TESE is to provide objective and analytical tools for problem identification of engineering systems, assist in forecasting the future evolution of agricultural technology, and recommend solutions for innovation of engineering systems based on their evolutionary stage. Applying evolutionary analysis to the engineering systems guarantees a supply of novel ideas, trimming recommendations, and conceptual directions.

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