New Governance Approaches to Prevent the Collapse of Complex Socioeconomic Systems

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Abstract

Modern socio-economic and technological systems are constantly becoming more complex, and as a consequence, the risks of their failures are increasing. Effective management requires tools appropriate to the new challenges. Complexity science offers a number of concepts that individually help to cope with increasing complexity and its effects to a greater or lesser extent. However, a more effective approach is their skillful synthesis, which allows to cover the system holistically, to identify the origin of potential crises and catastrophes that would otherwise remain «hidden», and to outline preventive corrective measures. The article presents a review and comparative characterization of paradigms of perception of complex systems extrapolated to the sphere of management. Using multilayer causal analysis, the case of two high-profile disasters that occurred with Boeing airplanes is considered. The concept of «orphan systems» is proposed, which allows to catch weak signals about the dangerous drift of the system, to react in time and take an appropriate managerial actions.

Keywords: management science; strategies; holistic approach; complex socio-economic systems; risk management; technological innovation; dynamic complexity; transformation; competitiveness

Citation: Katalevsky D. (2023) New Governance Approaches to Prevent the Collapse of Complex Socioeconomic Systems. *Foresight and STI Governance*, 17(3), 56–67. DOI: 10.17323/2500-2597.2023.3.56.67

Introduction

Complex systems have been and to a large extent remain the terra incognita of modern management science. Despite the enormous increase in knowledge about dynamic complexity achieved in natural sciences and engineering and the growing interest in relevant tools, the understanding of this phenomenon remains fragmented and blurred, which does not allow for capture it fully. Given the variety of methods for describing complex processes and systems, in most cases the latter's behavior can only be explained post factum. Although they are believed to be unpredictable, in some cases it is possible to identify the forces that determine their development vectors.

This paper attempts to classify the existing approaches to describing and managing complex socioeconomic systems. Using the multilayer causal analysis method, the Boeing case was explored, which illustrates how the lack of a holistic approach to a complex production system and the failure to understand the nature of its hidden transformations did not allow for the detection of weak signals, harbingers of disasters, in time and subsequent switch of the system into safe mode.

This paper begins with an analysis of modern scientific paradigms of complex socioeconomic systems' perception: their initial assumptions, features, and predictive potential. Then the two crashes of Boeing 737 MAX aircraft (in 2018 and 2019) are analyzed as examples of major failures of complex social systems. An attempt was made to identify the underlying causes of the system's collapse in the scope of one of the paradigms. The author's vision of the dynamics of complex socioeconomic systems' development is proposed. The "orphan system" and "system drift" concepts are introduced, which help one to better understand the processes taking place in the systems under consideration and the logic of their changes.

Management Paradigms of Complex Systems

The professional community identifies four main complex system perception paradigms, each of which, with their respective strengths and limitations, can enrich management practices.

Mechanistic paradigm. Complex socioeconomic systems are compared with corresponding feedback-driven technical systems based on the interactions between their elements (Rosenblueth et al., 1943; Wiener, 1948; Boulding, 1956; Von Bertalanffy, 1950; Forrester, 1969, 1971). This modeling area is currently known as system dynamics (Richardson, 1991; Sterman, 2002). The origins of this approach are sometimes traced back to Isaac Newton's works. In economics it was first applied by Adam Smith, but has reached its prime with the rise of Taylorism in the 20th century. The economy is seen as an equilibrium machine brought to balance by an external force: the "invisible hand of the market". It can be represented as a model, albeit a simplified one (Raskov, 2005). From the standpoint of a mechanistic, engineering perception of the world, the more complex the system, the more unpredictable is its behavior and the higher is the probability of its elements' failing. Automation strengthens the links between system elements and subsystems, so the system becomes less and less controllable (Perrow, 1999). Various failure warning mechanisms only complicate the system, thus increasing the risk of accidents further. Many large, resonant catastrophes resulted from such processes and thus can be classified as "natural". Detecting weak signals (harbingers of accidents) is a way to minimize risks, but this approach often does not work because by the time "sufficient" information is obtained, no time to respond is left (Ansoff, 1979).

The ***natural science paradigm*** extrapolates natural sciences' patterns (mainly from physics and chemistry) and applies them to socioeconomic systems. Its main areas include econophysics and synergetics. Researchers with a background in physics who have devoted themselves to studying economic matters, primarily financial market-related, work in this area. Concepts such as power laws of distribution, phase transitions, diffusion, correlation, turbulence theory, and so on are applied. This is justified by the fact that it is impossible to perform large-scale experiments in economic theory and finance, so one cannot do without statistical physics tools. Financial markets are seen as non-linear complex open systems. Econophysics gained momentum in the 1980s thanks to the work of the Santa Fe Institute researchers (Arthur, 2001; Mantegna, Stanley, 1999; Sornette, 2003; Helbing, 2012; etc.), and in its turn contributed to the development of an agent-based simulation method which describes market players' interaction using physics principles. Synergetics studies complex systems' self-organization (Haken, 1981; Prigogine, Stengers, 1984; Ebeling, Feistel, 1986; Kurdyumov, 2006; etc.)

Self-organization is defined as non-equilibrium processes that under the influence of systemic driving forces lead to the emergence of more complex structures. One of these processes is a thermodynamic equilibrium: a mechanism describing complex chemical reactions similar to phase transitions in physics (Prigogine, Stengers, 1984; etc.). In their development, complex systems periodically come to bifurcation points characterized by high uncertainty, so even minor events can radically change the course of the system's evolution. Proponents of this approach suggest that the system's behavior can be predicted through identifying the order-defining parameters (attractors), which are few. They are determined by the behavior of system elements and subsystems in dynamics, but then suppress them and set the vector for the whole system. Knowing potential attractors and understanding the laws of complex systems' evolution makes it possible to predict their path with a certain probability. By affecting complex systems near bifurcation points, one can turn their further development toward a preferred direction, since "when passing through forks, the environment becomes sensitive to collective and individual actions which can lead to the emergence of new social, cultural, technological, and other patterns" (Knyazeva, 2020).

The ***evolutionary biological paradigm*** uses the biological metaphor and the evolutionary mechanism concepts to describe complex socioeconomic systems (Schumpeter, 1912; Alchian, 1950; Moore, 1993; Nelson, Winter, 1985; etc.). This approach is primarily reflected in the "evolutionary economics" theory according to which markets, as complex systems, dynamically change over time due to competition and survival of the fittest (Williamson, 1996; Beinhocker, 2006; Dosi, 1982; etc.). Change is open and determined by heredity and survival. Business processes can be changed by introducing new practices and technologies and passed on to new generations of economic agents like genetic information. Change can be intentional or accidental. Survival is determined by the effects of the external environment (market); the fittest take root in it, which corresponds to the logic of innovation dissemination. According to this new look at adaptation, companies not only adapt to the external environment, but can themselves change it to suit their needs, creating market niches (in the economic context, territorial clusters, value creation ecosystems, industry-specific competition rules, etc.) (Nelson et al., 2018). Macroevolutionary leaps do not add up to a set of microevolutionary changes but are also explained in terms of macrolevel phenomena such as behavioral patterns. As the animal world adapts to climatic and geological changes, so complex social systems have to adapt to changing external conditions.

The ecosystem paradigm is one of the mainstreams of modern strategic management, based on the competitive cooperation and the development of business ecosystem concepts. A popular tool is multi-agent modeling, which reproduces agents' behavior (individuals, organizations, and other autonomous subjects), the rules of their interaction, and the environment in which they operate. The behavior of the entire system (at the macro-level) is determined by the numerous strategies of individual agents who imitate each other, "infect" each other with ideas and rules, and thus create the emergent behavior phenomena. The computational power available today allows one to describe agents' actions in nuances and build sophisticated models. For example, consumer behavior is studied taking into account rational and irrational decision-making aspects (cultural and religious ones) as well as multi-criterial and context-based choice situations. (Katalevsky, 2015). Agent-based modeling allows one to visually trace how small, and seemingly secondary, factors that determine players' behaviour and interaction lead to significant social consequences (Wilensky, Rand, 2015).

Anthropocentric paradigm. This is the only approach to complex systems focused not on the complex processes as such or on adaptive ecosystems, but on the individual who makes the decisions and their motives. In our opinion, this approach seems to be the most objective in comprehending complex social systems and serves as the basis for a realistic assessment of their development. It blends the achievements of economics, sociology, psychology, management science, and political science. The essence of individual and collective human behavior is studied, along with the specifics of people's interactions with the environment and the logic behind their choices (Simon, 1972; Deming, 2000; Lindblom, 2001; Schelling, 1978; Ackoff, 1978; Mintzberg, 2013; Akerlof, 2000). The growing popularity of the anthropocentric paradigm is in line with economists' growing interest in studying the substance and motives of human behavior (Kahneman et al., 1982; Thaler, 1994; Sunstein, 2014; Ariely, 2008; etc.). Economic processes are perceived as emerging social phenomena determined by group interactions (Andersen, Nowak, 2014). Sociologists call such phenomena "constructing social reality" (Berger, Luckmann, 1966). Several levels of systems analysis are typically distinguished: micro-level (individual choice), meso-level (group decisions)[1], and macro-level (the entire economic system) (Dopfer, 2004). In the first case, the combined decisions determine the behavior of a person, in the second of a group, and in the third of the entire macrosystem. The process evolves along the chain from the micro to the macro level and is described by the unintentional segregation model (Schelling, 1978). It has been proven that individual behavior is not always rational; its nature is much more complex than previously thought (Simon, 1972; Kahneman et al., 1982). Since the early 2000s the identity theory has been gaining popularity, which emphasizes the importance of the social group with which an individual identifies (Akerlof, Kranton, 2010). The perception of stories (narratives) determines individual economic strategies which affect the macroeconomic system's behavior as a whole.

The main characteristics of the four approaches described above are structured in Figure 1. Their features largely determine the range of solutions they offer and their limitations. The choice of approach in many ways defines the result.

Limitations of the Considered Approaches

The limitations of the technical paradigm based on the "Fix it!" logic are due to the fact that a complex system can only be "fixed" a posteriori, i.e., after a "breakdown". Further, often it is impossible to comprehend in which part of the system a problem will arise. Neither the human factor, nor the socio-cultural context

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[1] At the same time different concepts of a group can be used (several people, or a social stratum).

Figure 1. **Main Scientific Paradigms for the Perception of Complex Systems**

Natural science

Bottom line: complex systems' behaviour is determined by the universal laws of natural sciences

Slogan: "Calculate!"

Tools: mathematical modelling, physics and chemical laws as applied to social systems

Scientific fields: econophysics, synergetics, catastrophe theory, etc.

Mechanistic (engineering)

Bottom line: social systems as complex technical mechanisms which require design, maintenance, and repair

Slogan: "Fix it!"

Tools: system dynamics, discrete-event simulation, system engineering tools

Scientific fields: general systems theory, systems engineering, simulation modelling

Anthropocentric

Bottom line: complex social systems' behaviour as a result of complex, multidirectional activities of people

Slogan: "Design!"

Tools: sociological, behavioural, and psychological laws applied to social systems

Scientific fields: decision theory, organisational behaviour theory, behavioural economics, identity economics, constructivism, narrative theory

Evolutionary biological

Bottom line: complex social systems' behaviour is described by biological and ecological laws

Slogan: "Adjust!"

Tools: biological and ecological laws applied to social systems, agent-based simulation

Scientific fields: evolutionary economics, management (strategic, innovative)

Source: author.

are taken into account. Effective organizations tend to apply interconnected, highly integrated processes and routines that allow complex work to be completed on time. However, if an error "penetrates" such a structure, it rapidly "infects" the entire system. An analysis of 80 complex technical system failures in the UK showed that the more a hierarchical organisation strives for order based on bureaucratic procedures, the more prone it is to errors (Turner, 1978). Excessive ordering of business processes increases the likelihood that work will be done according to plan, but at the same time errors will be reproduced and replicated throughout the system. Thus, complex systems' failures can be caused both by violating the order and excessively increasing it. A healthy organizational management process is achieved by avoiding excessive control, building a less rigid hierarchy, coordinating autonomous teams' operations, encouraging diversity of opinions, and flexibility in decision-making (Weick, 1998).

The arsenal of the natural science paradigm primarily includes complex mathematical tools (chaos theory, correlation, time series, etc.). Its limitation is that individual behavior and motives cannot be mathematically calculated. This approach can be used to describe certain phenomena such as, e.g., group behavior during emergency evacuations or price fluctuation patterns on financial markets. However, since the human factor with its complex motives is removed from these models, they do not allow one to holistically interpret complex phenomena.

The evolutionary biological paradigm is actively applied in present-day strategic management because it offers effective analogy models and "working" strategies (such as co-evolution, "competitive cooperation" (co-opetition), etc.). Since even large companies find it difficult to compete on their own, the "joining the pack" approach appears to be promising. Organizations create their own ecosystem or join the dominant one. However, this model also greatly reduces the choice of strategies, since adapting is not always the only right way nor does it guarantee long-term survival, which is confirmed by numerous historical examples. Real life is much richer and offers a wide variety of options.

The anthropocentric paradigm proceeds from the understanding that a person's actions are determined by their identity and by socio-cultural factors, so it proposes to focus on designing social systems (hence its notional slogan "Design!"). It is quite popular with institutional economists who pay particular attention to the norms, laws, and cultures which determine economic behavior.[2] Other approaches, with the exception of the anthropocentric one, prefer "not to see" individu-

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[2] The importance of this approach is indirectly confirmed by the Nobel Prize awarded to a number of economists who can be counted among the supporters of the anthropocentric paradigm: Herbert Simon (in 1978), George Stigler (1982), Douglas North (1993), George Akerlof (2001), Daniel Kahneman (2002), Robert Aumann and Thomas Schelling (2005), Elinor Ostrom (2009), and Richard Thaler (2017).

als, which is reflected in their terminology (McCloskey, 1993). For example, the technical and econophysical paradigms "animate" complex systems: according to them, the latter "adapt", "develop", "interact", etc. Complex systems are presented as self-sufficient objects endowed if not with reason, then with high autonomy. Man as a manager is excluded from consideration. Still, the technical paradigm indirectly implies that complex systems' mechanisms must be designed, maintained, and, at least occasionally, repaired by someone. That is, the individual is the subject, while the complex system is the object of management.

It seems that the mechanistic, natural science, and evolutionary paradigms of illustrating complex systems, despite using different perspectives, still do not adequately describe social systems. An exclusive reliance on them will inevitably lead to methodological errors when it comes to analyzing individuals' complex behavior mediated by the social context, specific worldviews, and traditions. Unlike the other approaches, the anthropocentric paradigm blends the widest layer of interdisciplinary research in economics, sociology, psychology, and management, and thus, in our opinion, allows for the most realistic modeling of human behavior in complex systems. A good example of the anthropocentric approach is the "garbage can theory" (Cohen et al., 1972), which has greatly influenced economics, sociology, and management. It challenged the prevalent rational decision-making paradigm at the time by offering the most realistic description of the process. Among other things it was applied to explain the causes of technical disasters (Sagan, 2020).

From the point of view of managing complex socioeconomic systems, analysing the system built around the production of Boeing passenger aircraft, and the specifics of the US aircraft industry regulation is of great practical interest. This case, viewed through the prism of anthropocentric approach, shows how the evolution of complex relationships between various influence groups inside and outside Boeing has led to high-profile technical disasters.

Boeing 737 MAX Case Study: A System Error that Cost 346 Human Lives

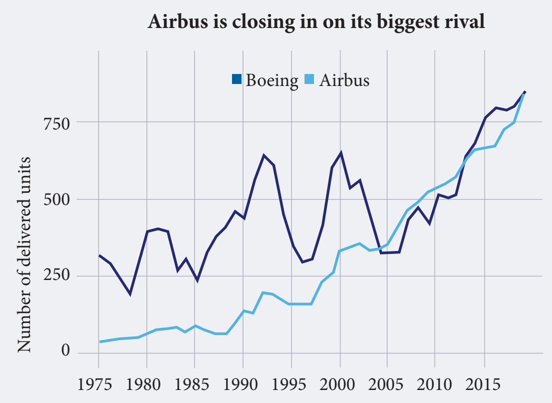
At the end of the last decade, two dramatic accidents happened within several months of each other, both related to Boeing, a long-term global aircraft industry leader. In the fall of 2018, a Lion Air flight crashed, and in the spring of 2019, an Ethiopian Airlines flight also crashed. In both cases the aircraft were from the Boeing 737 MAX series, which were approved by the US Federal Aviation Administration (FAA) as safe to fly two years earlier. Together, the two tragedies claimed 346 lives. By the special FAA order of 13 September 2019, all Boeing 737 MAX aircraft in the United States were grounded pending the completion of an investigation; three months later Boeing suspended the production of this aircraft series and fired the CEO. What is of interest in this story is not so much the technical causes of the disaster, as the answers to the questions concerning which systemic factors led to these events, when did these factors arise, how they evolved, and whether it was possible to prevent the tragedy. We are talking about a complex socioeconomic system that is subject to one of the most stringent, thorough, and technically advanced regulation in the world. How did the actions of various interest groups lead it to gradually evolve into a "orphan system" that failed on a massive scale? Our analysis is based on the findings of an independent investigation of the incidents in question, conducted by the US authorities (HCTI, 2020).

Technical Explanation of the Causes of the Disaster

According to experts, the Boeing 737 series is a global civil aviation "bestseller": over 15,000 aircraft have been sold in total. The Boeing 737 MAX modification was Boeing's answer to its main rival Airbus's plans to launch an improved version of the A320 aircraft - the A320neo, 14% more fuel-efficient than its predecessors. To match the rival design, the 737 MAX series was given larger, upgraded engines. The company positioned this aircraft as being similar to the flagship model (737), which made it unnecessary to retrain pilots for flying it. However, the use of larger engines necessitated structural changes, which in certain cases caused the aircraft to destabilize during flight. In an attempt to eliminate this factor, Boeing developed the Maneuvring Characteristics Augmentation System (MCAS), which automatically corrected the plane's position in the air. When the aircraft was under manual control, the MCAS was supposed to be activated by the pilot. But, as it turned out during the investigation of the disasters, in some cases the system failed: many times it engaged on its own. Further it was impossible to turn it off or put the aircraft into manual control mode (HCTI, 2020).

After the first crash, Boeing blamed the pilots for being underqualified. Only after the second accident did the company acknowledge the problems with the MCAS. In a critical situation the pilots were expected to deal with it by switching the aircraft to manual control mode. But as was noted, no additional pilot training was carried out. Further, it turned out that switching to manual mode was impossible in principle, since during MCAS operation this mode was turned off by default. Errors in the MCAS design violated the main design regulation, according to which automated systems' operation must not hinder the actions of the pilot (HCTI, 2020). After the two accidents Boeing made a number of technical improvements to the MCAS: more sensors were added, the possibility of its spontaneous engagement during the flight was eliminated, the opportunity to switch to manual control was ensured, and additional pilot training was conducted. However, the aircraft design and software faults do not fully explain why things "went wrong". To understand the reasons, one must look at deeper corporate culture issues.

Figure 2. **Comparison of Airbus and Boeing Output Growth**



Source: author, based on: https://finance.yahoo.com/news/1997-merger-paved-way-boeing-090042193.html, accessed 17.02.2023.

Features of the Boeing Corporate Culture

Established over a hundred years ago by the experienced pilot William Boeing, the company quickly began to receive orders from the US Navy, which facilitated its subsequent rapid growth.[3] The founder created a culture that could be described as "a community of engineers dedicated to building excellent aircraft" (Frost, 2020). It was based on a philosophy of increased attention to detail, in line with the belief that neglecting cause-and-effect relationships leads to incorrect interpretations, which, in turn, results in making wrong decisions.[4] In 1960-1970 the US air transportation industry was heavily regulated, the market did not grow particularly rapidly and the competitive pressure on Boeing was not high. However, with the deregulation of the sector and the rise of competition (Figure 2), the company faced the need to optimize costs. In 1997 Boeing merged with McDonnel Douglas. At the time such a deal seemed to be a perfect solution for both parties: Boeing was the leader in civil aircraft construction and McDonnell Douglas got an opportunity to make a leap to the top on the strength of its partner's competencies. Otherwise, developing a new competitive aircraft would require $30 billion and 10 years of work, provided that competitors would not make any progress during that time (Callahan, 2020). This has changed the corporate culture: the focus on solving complex engineering problems was replaced by the desire to increase financial gains. However, in the clash of the two parties' corporate cultures, the philosophy of the smaller McDonnell Douglas prevailed. As a consequence, Boeing has shifted from its emphasis on solving complex technical problems and conducting costly breakthrough research to increasing profits by cutting costs and abandoning radical innovation in favor of upgrading older models (Frost, 2020).

Boeing employees had a hard time adapting to the new philosophy, which contradicted their main value: "making excellent aircraft" (Greenberg et al., 2010). The focus on minimizing costs and maximizing profits created "fertile" ground for "replicating" technical errors. Industry experts estimate that in 2011 the cost of designing a new aircraft would be $10 billion, while repurposing the 737 MAX from the 737 NG series model only cost $3 billion. In seven short years, the gradual effect of these destructive forces led to two major disasters. What seemed to be just an unacceptable engineering error (the MCAS problem), actually had deep roots: a new driving motivation focused on short-term financial results. However, the landscape of the possible causes of the crash would not be complete without examining how the technical issues were overlooked by the key industry regulator, the Federal Aviation Administration (FAA).

Miscalculations of the Industry Regulator

The 737 MAX development team was under intense pressure from management to get the aircraft to market faster. As a result, a "concealment culture" evolved at the company, which amounted to misinforming the FAA – the agency responsible for the certification of all aviation equipment supplied to the US market. Since the FAA did not have sufficient human resources to independently perform all necessary tasks, it had the right to delegate some of its certification responsibilities to qualified third-party professionals (Figure 3). These professionals, known as "designated engineering representatives", were employed (and paid) by Boeing, but reported not to the Boeing management but to the FAA supervisors. They were the FAA's "eyes and ears" in the field, thoroughly familiar with the intricacies of the certification process and believed to take an unbiased approach to certification. This practice was first implemented by the FAA in the 1950s and has since evolved towards a gradual expansion of the FAA field representatives' powers (Figure 3). This approach was applied to well-known, low-risk technological solutions. It allowed the FAA to focus solely on assessing high-risk technologies (projects critical to safety or radical innovations). However, in reality this "strategy" led to ignoring a number of certification requirements, which also contributed to the Boeing aircraft disasters.

Figure 4 shows the gap between the rate at which new technologies subject to certification are introduced by the industry and the FAA's "throughput capacity" (internal resources to process applications). In the case

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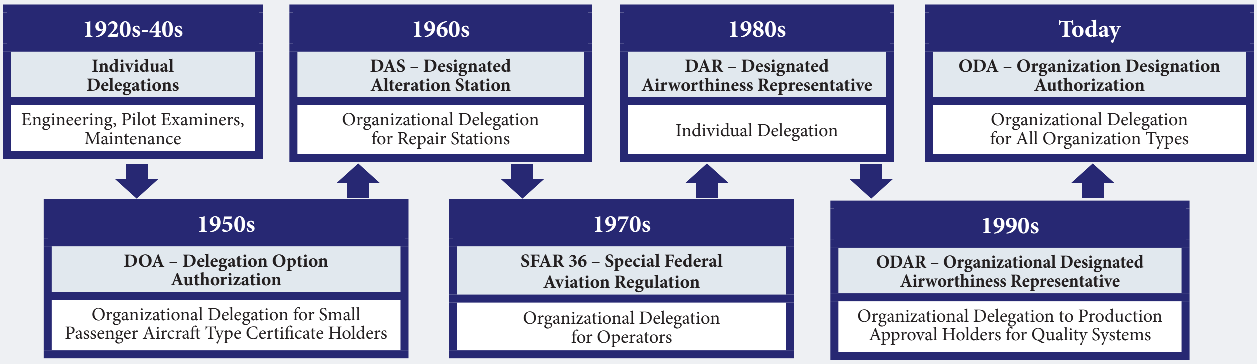
[3] https://www.businessinsider.com/how-boeing-737-max-plane-became-best-seller-2019-3, accessed on 14.04.2023.

[4] https://www.boeing.com/history/pioneers/william-e-boeing.page, accessed on 19.03.2023.

Figure 3. **Development of the FAA Certification Delegation System**

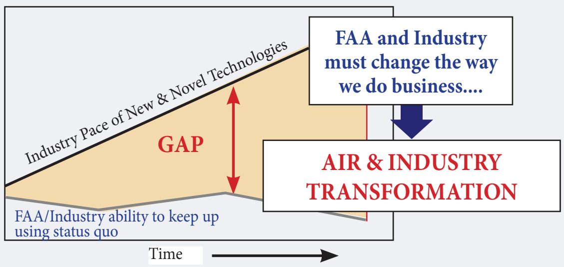


Source: adapted by the author from (HCTI, 2020).

of the Boeing 737 MAX in 2013, the FAA delegated 28 of the 87 certification operations to the company itself. By the end of 2016, this ratio was already 79 to 91. According to the findings of the investigating panel, the FAA “outsourced” to the aircraft manufacturer too many certification responsibilities (OIG, 2020). Plus, seemingly minor changes were made to the delegation regulations in 2005, which, as it turned out later, had a significant impact on the certification process and its results (Figure 5). Under the previous system, designated engineering representatives, despite being fully funded by Boeing, reported directly to the FAA. With the introduction of the new system, Boeing itself gained the right to appoint such experts (Figure 5); they handed the information over to their managers, who processed it and the passed it on to the FAA (a similar system was approved by the FAA itself).

A few months before the first crash, Boeing and the FAA jointly collected and published statistics according to which in 2010-2018 civilian air carriers had a single fatal accident. Overall, US civil aviation fatalities (per 100 million passengers carried) over the past 20 years have fallen by 95%.[5] Excessive complacency with such a picture has led to a gradual relaxation of the FAA control of certification processes. However, the MCAS was not the first technical issue that the FAA missed. A few years earlier problems with the spontaneous combustion of lithium-ion batteries in the Boeing 787 Dreamliner series were discovered during commercial operation of the aircraft. As with the MCAS later, all aircraft in the series were grounded pending the completion of an investigation. During the certification one of the FAA engineers suggested putting the batteries in a steel case, but Boeing rejected this recommendation, and the FAA officials went along with the company’s decision. Only after several spontaneous combustions and the complete termination of all Dreamliner flights was the steel casing idea implemented (HCTI, 2020). Thus, even before the Boeing crash, the FAA’s supervision delegation system was failing. However, these failures were seen as rare occurrences, so the general certification procedure remained largely unchanged.

Figure 4. **Gap between the Rate of New Technology Development and FAA Certification Potential**



Source: author.

There is another critical factor in the process under consideration: a conflict of interest in the form of the manufacturing company’s pressure on FAA experts. As of 2013 the FAA began to survey its designated representatives and in 2016 the company got involved too. Many respondents reported being pressured, to varying degrees, by Boeing’s management to speed up certification. Distorted communication between Boeing and the FAA (information was funnelled through a double filter) served as an aggravating factor. For this reason, the FAA was unable to adequately assess the risks associated with technical flaws in the design of the MCAS.

An analysis of the chain of factors that led to the disaster allows one to build a hierarchy of underlying causes of the system’s degradation. The main factor was the shift in Boeing’s values hierarchy (flight safety faded into the background in favor of maximizing financial

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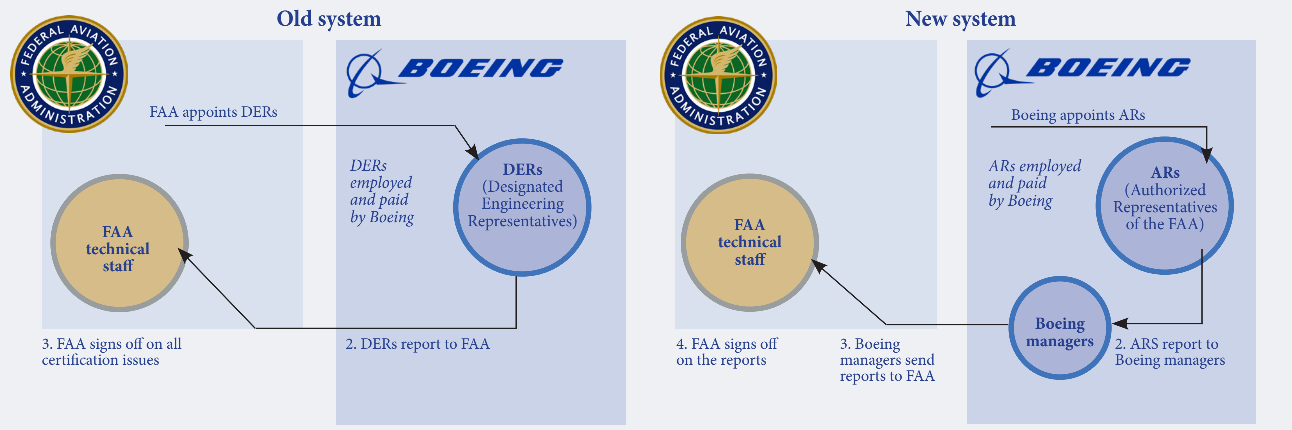
[5] https://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=22975, accessed on 18.02.2023.

Figure 5. **Previous and New FAA Delegation Procedures**



Source: author, using: https://www.pulitzer.org/winners/dominic-gates-steve-miletich-mike-baker-and-lewis-kamb-seattle-times, accessed 17.02.2023.

results), which led to a "shortening" of strategies' lifespan. The changes in the FAA certification system also made a contribution (Figure 6).

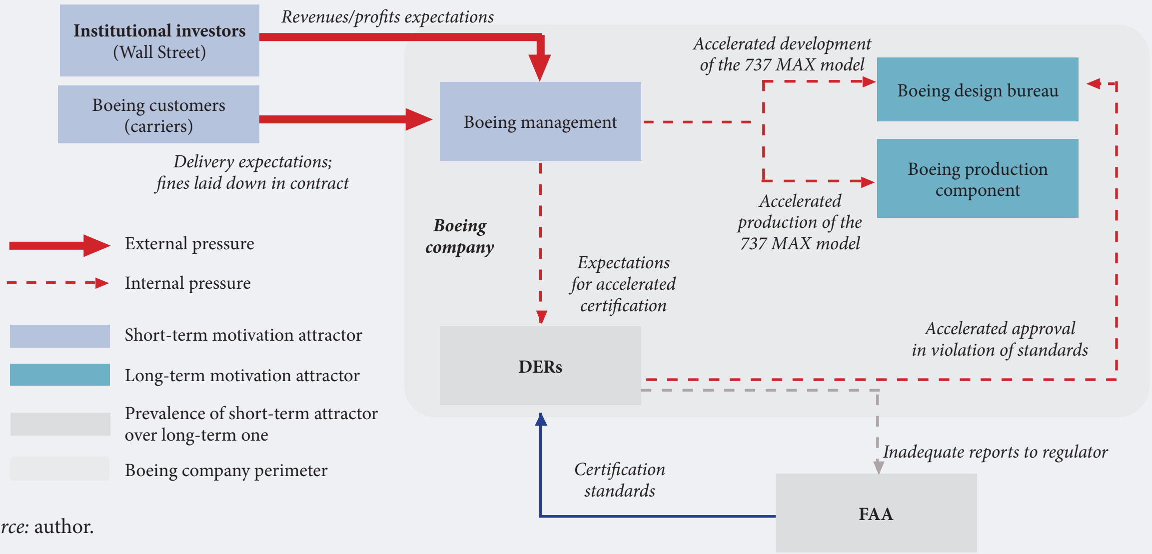
Boeing 737 MAX Production Race

The report by the experts who investigated the causes of the tragedies highlights the "production race" for the Boeing 737 MAX assembly. The company sought to deliver the aircraft to customers as quickly as possible. If in 2010 the output was just over 30 aircraft per month, in 2014 this figure reached a record for Boeing at that time at 42, and shortly before the first disaster it was planned to increase it to 57. The focus on stepping up the financial indicators replaced the more important goal of introducing the most advanced safety technologies and innovations in general, leading to an increased load on production facilities.[6] Taken together, all this caused a serious degradation of the flight safety system.

The Evolution of Complex Systems: Why Failures are Inevitable

We have described the "orphan system" phenomenon using the development of Boeing 737 MAX aircraft series as an example. Any complex system has internal contradictions of some kind due to its inherent multidimensionality and multiple "tension points" arising due to various internal and external forces. The system becomes "orphan" when its key players refuse to perceive it as a whole and take responsibility for its long-

Figure 6. **Diagram of Motivational Factors of the Main Players in the Boeing 737 MAX Case**



Source: author.

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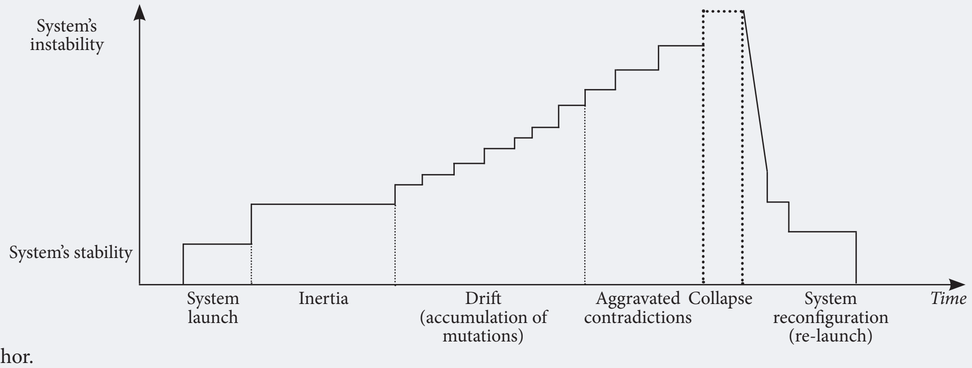
[6] https://www.seattletimes.com/business/boeing-aerospace/737-problems-have-grown-in-rentondespite-boeings-reassurances, accessed on 17.02.2023.

Figure 7. **The Evolution of "Orphan" Systems**



Source: author.

term sustainability. Instead, the problem is passed to another player (and sometimes to subsequent generations, as, e.g., in the case of the natural environment). This system state becomes a natural outcome when internal contradictions gradually intensify over the course of the system's drift. The drift happens as follows: first, there is a slow accumulation of errors ("mutations") which is hard to analyze objectively; values and fundamental principles deform, the planning scope shifts from long to short term. The danger is that the organizational system misses this process altogether due to its gradual and prolonged nature. As a result, the system loses its "owner" and starts to change under the influence of the dominant "pressure" vector.

Several factors have become critical in the process of the complex US civil aircraft manufacturing regulation system turning into a "orphan" one. The system drift was mainly driven by changes in the company's culture, the shift of the motivational factor from long term (passenger safety) to short (annual financial result), and the FAA's new aircraft certification policy which created a conflict of interest with the company's management. Communication distortions due to the fact that information from the company could only reach the FAA after passing through several "filters" made additional contribution. As a result, the regulator simply could not detect technical problems in time.

Principles of "Orphan" Systems' Evolution

Complex systems can be in a stable or unstable state. The transition from the first to the second happens in several stages (Figure 7):

1. *Creation and launch.* The system's foundation is laid, its development vector is set, and links between the elements established.

2. *Inertia.* The system develops in accordance with its basic value principles.

3. *Drift (accumulation of mutations).* The system gradually begins to change under the influence of internal and external stakeholders, accumulating "mutations". Its elements deform, while the links between them and the basic principles are eroded (at Boeing, this process began in the 1990s).

4. *Aggravation of contradictions.* The system gradually moves away from its basic principles. Conflicts between goals, objectives, and values increase, communications become distorted.7 Instability arises, contract and project deadlines are no longer met, even intermediate objectives are failed. All resources are thrown toward finding quick solutions, which worsens the situation further: each element is only interested in "saving itself". The system arrives at the pre-collapse stage.

5. *Collapse.* The accumulated contradictions lead to a major failure which causes the partial or complete destruction of the system. As our analysis shows, it was "programmed", inevitable, albeit delayed.

6. *Intervention.* The system is reconfigured and updated. After that, if the lessons have not been learned, the cycle described above repeats.

This process is common for all types of organizations and socioeconomic systems. The larger the system, and the tighter its elements are interlinked, the more prone it is to become "orphan". Holistic thinking and understanding complex systems' behavior allows one to detect the emergence of a destructive drift in time and take steps to push the system toward the desired direction.

Conclusion

The paper analyzes the little-studied "orphan" systems phenomenon. More complex socioeconomic systems imply an increased number of participants and stronger interconnections between them. At the same time, key system participants' basic values deform, while communications and links in the original system architecture get distorted. The system begins to change under the influence of multidirectional pressure vectors from interest groups, gradually drifting toward

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[7] From R. Ackoff's speech. https://www.youtube.com/watch?v=EbLh7rZ3rhU, accessed on 18.04.2023.

collapse. Only a timely and adequate managerial intervention can reconfigure the system and direct it along the desired path.

Complexity science offers a number of concepts which, individually, can to some extent help companies and organizations of different sizes cope with increasing complexity and its effects. However, a more effective approach is skilfully blending them, which allows one to holistically address the entire system, identify the origins of potential crises and catastrophes (which would otherwise remain "hidden"), and outline relevant preventive measures.

This paper presents an overview and a comparison of complex systems' perception paradigms extrapolated to the field of management. Using multilayer causal analysis, the case of two resonant disasters with Boeing aircraft is considered, which most vividly illustrates the emergence of "orphan" systems. However, no matter how destructive the effects of the system's degeneration in the course of its implicit and extended transformation are, it is always possible to reconfigure and improve it with the help of holistic thinking and understanding the nature of complex systems.

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