Theory of Innovation Failure and Application in Aerospace Missions

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Abstract

In markets having innovation-based competition, one of the fundamental problems is the high risk of failure in new innovation projects that generates negative effects on organization performance and related competitive advantage. This study here seeks to provide a general theoretical framework to clarify the concept of failure and related properties in organizational setting. The failure here is a set of errors, which in turn includes a number of faults. Failure is caused by the impossibility of the system to make advances towards the principal goal of the design intent in order to take advantage of important opportunities or to cope with environmental threats. The theoretical framework is applied in two main study cases of aerospace missions, given by: spacecraft Soyuz 1 in 1967 and STS-10/ Space Shuttle Columbia in 2003. Theoretical framework here can guide, when a failure occurs in innovation processes, R&D managers, designers, analysts, etc. to strengthen strategic management and communication in order to maintain the goals of organization in the right direction in turbulent environment.

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1. Introduction

Goal-setting of innovation is one of the fundamental aspects in strategic management to increase firm, and in general organization, performance, to achieve and sustain its competitive advantage (Teece et al., 1997). However, in turbulent markets with rapid changes, the risk of failing the goals of innovation projects can have a high probability in specific industries (e.g., pharmaceutical, aerospace, etc. cf., Sun et al., 2022; Qin et al., 2005; Celikmih et al., 2000; Li and Hou, 2022) and can generate negative consequences in organization, such as large firms can waste a lot of investment, miss commercial opportunities, whereas in small enterprises a goal-failure can also destroy the business in markets (Forsman, 2021; Taylor, 2021, 2022). Studies show that failing high and specific goals about innovation projects can be damaging for organizational behaviour and outcomes in markets and management has to consider detrimental effects on organization and human resources when sets high and risky achieving-goal up in R&D of new innovation (Höpfner and Keith, 2021).

Cannon and Edmondson (2005) show that organizations can learn from failures and suggest a strategy of goal-achieving. In particular, achieving-goal strategy has to be implemented as an integrated set in organizational and managerial practices. Moreover, in the presence of a failure, the first stage is to analyze sources and foster learning processes to support next goals of challenging projects (Coccia, 2012, 2017; Denrell, 2003; Desai, 2015). Edmondson (2011) argues that many executives consider all failure events negatively, but this approach can impoverish organizational learning and lead to a misleading managerial behaviour that reduces the potentiality of reaction and organizational adjustment in markets with rapid changes. In fact, the goal-failure in new projects can be an inevitable event of market turbulence but it can also generate positive organizational effects in terms of learning for achieving future goals and improving organizational performance. Maslach (2016) shows that a flop in the development of incremental innovation leads firms to a strategy of persistence in the same technological trajectory, whereas a flop in the development of radical innovation generates a change of innovation avenue and also of strategic partnership.

In this context, the study here proposes a new theoretical framework of concepts of failure in organizational setting. Suggested theory of failure here, directed to implications for innovation projects, can improve strategic management and help R&D managers, designers, analysts, and scholars to be more precise in the detection and analysis of the type of failure and improve organizational communication for appropriate actions of problem solving. In fact, theoretical framework here clarifies the hierarchical structure of elements forming the failure and related properties that increase the specificity in organizational communication when a failure occurs to change current modes of cognition and action in order to take advantage of next opportunities or to face consequential threats, minimizing the occurrence of failures. In short, this study seeks to provide a general theoretical framework that may strengthen strategic management with best practices that guide R&D managers, designers, etc., when a failure in organization occurs, to manage properly flops and support organizational and managerial behaviour of firms towards the right direction to achieve designed goals and sustain competitive advantage in turbulent markets. The theory of failure is clarified here with some practical applications from study cases in aerospace industry.

2. Theory of innovation failure

2.1. Basic concepts

One of the main elements that supports competitive advantage of firms (and in general organizations) is new technology, which is driven by inventions of new things that are transformed into usable innovations in markets. The risk of failing the goal of innovation projects should be considered by managerial behaviour in order to minimize its occurrence and, as a consequence, reduce negative consequences in organizational structure and firm performance.

Failure is a complex concept that dissecting it, it includes different elements, given in increasing order by faults, errors and failures in the system of project (Figure 1):

- *Fault* (*flt*) is caused by the lack or scarcity of scientific, technical and physical elements, and misleading modes of cognition and action that lead, with other elements, to an error in a system (e.g., a project, an organization, etc.)
- *Error* (*err*) is caused by a set of faults that changes or alters the behavior of the system, decreasing the expected results:
  $\text{Let flt1} = \text{fault 1}, \text{flt i} = \text{fault i}, \ldots, \text{flt n} = \text{fault n} \Rightarrow \;\Rightarrow \text{Error(errj)} = \{\text{flt1}, \text{flt2}, \ldots, \text{fltn}\}, (\text{errj}) = \sum_{i=1}^{n} \text{flt}_i$
- *Failure* (*F*) is caused by a set of errors that leads to a deviation of the system from its main objectives. In symbols,
  $\text{Let err1}, \text{err2}, \ldots, \text{errj}, \ldots, \text{errm}, \text{error for j=1}, \ldots, \text{m} \Rightarrow \;\Rightarrow \text{Failure} = \{\text{err1}, \text{err2}, \ldots, \text{errj}, \ldots, \text{errm}\}, F = \sum_{j=1}^{m} \text{err}_j$

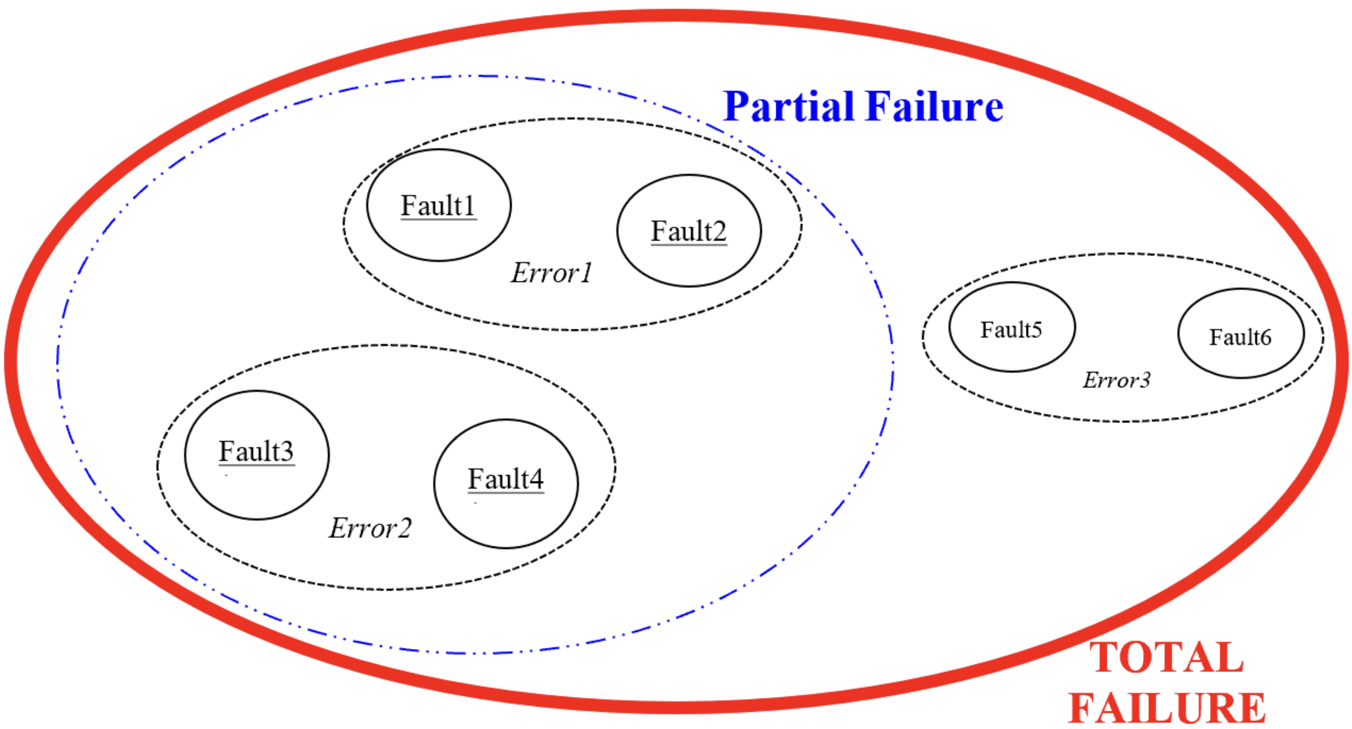

Figure 1. Faults, errors and (partial and total) failure

To put it differently, *failure* is caused by the impossibility of the system to make advances towards the principal goal of the design intent in order to take advantage of important opportunities or to cope with environmental threats (cf., Aytemiz and Smith, 2020; Cannon and Edmondson, 2005).

Failure of a system can be total and/or partial one (Figure 1).

- *Total Failure* is the non-achievement of the designed goal in its entirety and not only in some parts for manifold errors in the system: Total Failure = {err1, err2, …, errj, …, errm} = $\sum_{j=1}^{m} \text{err}_j$
- *Partial Failure* is the non-achievement of circumscribed and specific objectives, for some errors, in the overall design of main goal: Partial Failure = {err1, err2, …, errj, …, err m-1} = $\sum_{j=1}^{m-1} \text{err}_j$

Moreover, if Failure (*F*) and Success (*S*) are sets in a space of events. The complement **C**) of *F* is *S,* given by the set of element not in *F* (i.e., *S*=F$^{\mathbf{C}}$). The space of events can include Failure (F), Success (S) event and also Inconclusive Result (I, when there are no results that can be categorized as success with positive effects on system, or failure with negative effects on system, *see* Figure 2).

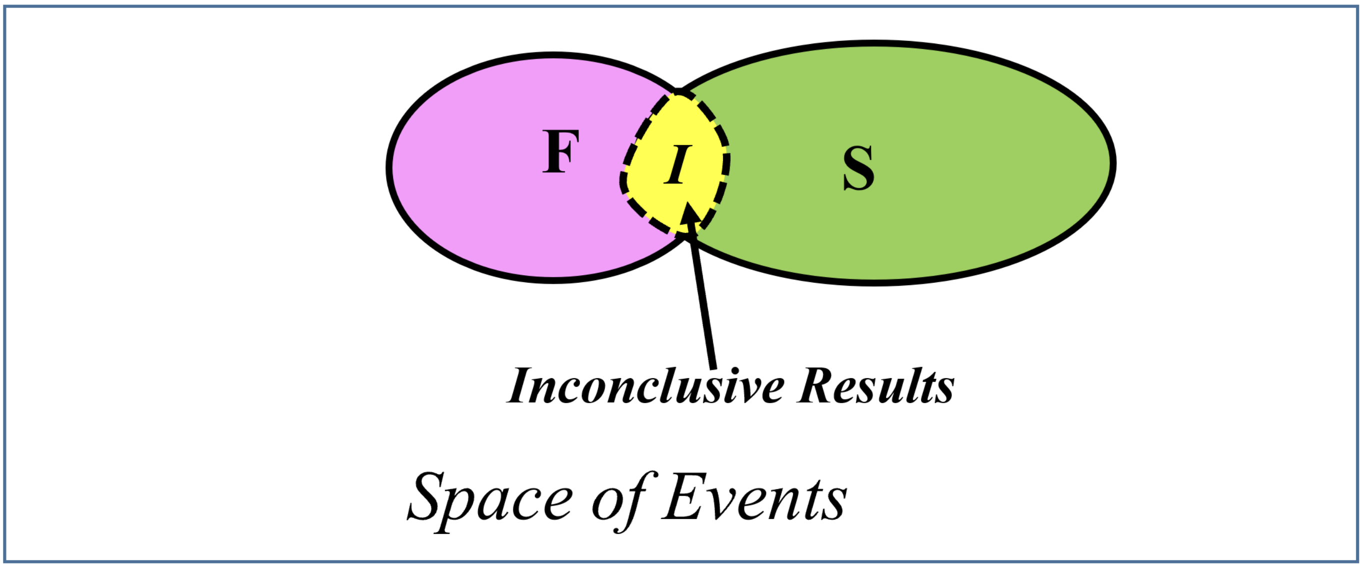

Figure 2. Failure F, Success S and Inconclusive Result (I) in the space of events

2.1. Properties of innovation failure

Let *flt = Fault, err = Error, F = Failure, S = Success and I = Inconclusive results*

1. *Inclusion condition*: flt ⊆ err ⊆ F
2. *Error condition: flt ⇒ err* (fault is a necessary but not sufficient condition for leading to an error in a system)
3. *Failure condition: err ⇒ F* (error is a necessary but not sufficient condition for leading to a failure in a system)
4. *Inconclusive results I: I = F ∩ S,* it is the event that contains elements of both F and S. *I* has common elements of F and S.

Moreover,

- Let F = Failure, *non*-F = *non*-Failure

1. Creation Condition: An organization A initiates modes of cognition and action to generate a process leading to δ-innovation
2. In a Condition of *F (Failure)*, organization A can face that:
    1. δ-innovation fails for predictable facts, events, problems, adjustable in R&D process
    2. δ-innovation fails for unexpected facts, events, problems, adjustable in R&D process
    3. δ-innovation fails for predictable facts, events, problems, unsolvable in R&D process
    4. δ-innovation fails for unexpected facts, events, problems, unsolvable in R&D process

Conditions 2a and 2b leads to *non*-F.

Conditions 2c and 2d leads to A's δ-innovation failure F.

2.3. Strategies to cope with innovation failure

– Adaptation

In the presence of an innovation failure (F), an organization α has a better adaptedness (A) than organization β in environment (E), if and only if α is better able to react to failure and learn than is β.

In short, α is better adapted to innovation F than β in E ⇔ A (α,E) > A (β,E)

– Learning process

Learning from innovation failure can take place only when an organization has a choice among alternative modes of cognition and action in the R&D process (cf., also Testa and Frascheri, 2015). In particular, learning, because of an innovation failure is directed to increase organization's efficiency in the pursuit of new processes under current and potential unchanging conditions (Levinthal and March, 1993; Madsen and Desai, 2010). Ackoff (1971) states that a system (organization in our case) learns how to adapt when it is continuously subjected to internal and/or environmental change, such that it increases the ability to maintain its efficiency under different changes. As a consequence, adaptation strategy can be learned.

Hence, innovation failure can improve strategic management and trigger positive effects in new R&D processes by what we can call *creative failure of new innovations* or *generative failure of new innovations* (Coccia, 2017; Sosna, 2010). Overall then, innovation failure needs a clear definition and concepts to improve organizational communication and design best practices of strategic management that create a new model of innovation directed to foster, with just mentioned strategies, the transition from the state of failure to the state of success in the process of R&D (Firestein, 2015; Schickore, 2021; Van der Panne, 2003).

3. Application in aerospace missions: case study

The application of the theory of innovation failure in the innovative projects of aerospace industry, where there is a high risk of failure (Hogeback, 2023; Quin et al., 2005), shows a main evidence of its consistency (Coccia, 2018; Coccia and Benati, 2018).

Two main case study are described.

Case study 1: spacecraft Soyuz 1 in 1967

Goal: Spacecraft Soyuz 1 is one of the first space vehicle intended to eventually reach the Moon. The mission plan for Soyuz 1 was to orbit Earth and then have a rendezvous with Soyuz 2 for an exchange of crew members before returning to Earth (Baikonur, 2023).

- *Fault 1A.* Problems began shortly after launch when one solar panel failed to unfold, leading to a shortage of power for the Soyuz spacecraft's systems.
- *Fault 2A*. Problems with the orientation detectors complicated maneuvering the craft. The automatic stabilization system was completely out of commission, and the manual system was only partially effective.

- The combination of fault 1A and fault 2A leads to an*error 1A* in the system of Soyuz 1.

Soyuz 2 modified the goal aimed to a launch that would include fixing the solar panel of Soyuz 1 and solve other technical problems in the space. However, because of a thunderstorms at cosmodrome that affected the booster's electrical system, the mission of Soyuz 2 is called off.

As a consequence, it is decided to abort the mission and Soyuz 1 had to re-enter in the Earth's atmosphere.

- *Fault 3A*. During the re-enter in the Earth, first drogue parachute of Soyuz 1 was deployed (a parachute designed for deployment from a rapidly-moving object). Because of a technical defect, the main parachute of Soyuz 1 did not unfold.
- *Fault 4A*. Flight director activated the manually deployed reserve chute, but it became tangled with the drogue chute, which did not release as intended.

- The combination of fault 3A and 4A leads to another*error 2A.* Error 2A leads to the impossibility for the spacecraft to slow down in the Earth's atmosphere.

- **Failure**. Soyuz 1 crashed into Earth on April 24, 1967 because of a series of faults combined in Errors 1A and 1B.

Learning processes. After the failure, Soyuz program is improved, mirroring the improvements made in the Apollo program after the Apollo 1 tragedy. The learning processes over time lead innovative projects of Soyuz that it is one the longest-lived and most dependable crewed spacecraft yet designed.

Case study 2: STS-10/ Space Shuttle Columbia in 2003

Another case study is the STS-107: Space Shuttle Columbia Failure in 2003 (Hogeback, 2023).

- The ramps of launch were covered in foam to prevent ice from forming that could damage the orbiter. During the STS-107 Space Shuttle Columbia launch, a piece of the insulative foam broke off from the Space Shuttle external tank, designed to insulate the fuel tank of the shuttle from heat and to stop ice from forming. The large piece of foam struck the thermal protection system tiles on the orbiter's left wing and created a hole (fault 1B).
- When the Columbia attempted a re-entry in Earth, initial fault 1 (hole in shuttle's left wing) has created another fault 2B: i.e., the damage of fault 1 allowed hot atmospheric gases to penetrate the heat shield.

- The combination of fault 1B and 2B leads to *error* in the system that has destroy the internal wing structure, which caused the orbiter to become unstable and break apart.

- **Failure**. The accumulation of faults and errors leads to failure with the total disintegration of the shuttle in the Earth's atmosphere (Hogeback, 2023).

Adaptation and learning process. To prevent future foam strikes, the external tank was redesigned to remove foam from the bipod. Moreover, electric heaters were installed to prevent ice building up in the bipod due to the cold liquid oxygen in its feedlines. Additional heaters were also installed along the liquid oxygen line, which ran from the base of the tank to its interstage section. NASA also improved its ground imaging capabilities at Kennedy Space Center to better observe and monitor potential issues that occur during launch. The existing cameras and along the coast were upgraded, and nine new camera sites were added. The camera on the belly of the orbiter was changed from a film camera to a digital camera to allow images of the External tank to be viewed on the ground soon after launch. The Orbiter Boom Sensor System, a camera on the end of the Canadarm, was added to allow the crew to inspect the orbiter for any tile damage once they reached orbit (Armstrong 2005, 2006; Jensen, 2005; Heiney, 2005).

As well as the updates to the orbiter, NASA prepared contingency plans in the event that a mission would be unable to safely land. The plan involved the stranded mission docking with the International Space Station (ISS), on which the crew would inspect and attempt to repair the damaged orbiter. If they were unsuccessful, they would remain aboard the ISS and wait for a rescue (Armstrong, 2006a).

4. Concluding observations

Innovation failures and errors are basic aspects of scientific and technological progress (Barwich, 2019; Borycki, 2013). This paper defines basic concepts and properties concerning the failure in innovation projects that clarify when a R&D process has a deviation from expected results[1]. This study highlights the temporary bounded rationality and limits in organizational behaviour in the development of innovation.

Different minor faults that lead to main errors in system and a consequential total or partial failure in innovation projects play vital aspects that boost the organization to extend the perspectives in the process of R&D by exploring, when a failure occurs, alternative and improved technological pathways and/or new directions of investigation to solve specific problems, reinforce the integrity of the system and advance science and technology to support organizational performance directed to achieve goals in the presence of environmental threats and unforeseen events.

We envision that this theoretical framework of failure in innovation projects can be used to:

1. clarify basic elements in the structure of failure in innovation projects designed, and
2. detect and discriminate different minor elements underlying the failure in innovation projects or activities to better understand ex-ante phases that should be improved in R&D process to support organizational performance in the intent of achieve expected goal.
3. provide a clear structure to improve the organizational communication related to innovation failure to design best practices of strategic management directed to minimize flops and support competitive advantage in markets having innovation-based competition.

To Conclude, as failure is a part of the process of new projects and programs, Barack H. Obama (44th President of the United States) properly said: “You can't let your failures define you. You have to let your failures teach you."

Footnotes

[1] This theoretical framework can be applied in different contexts: cf., Benati and Coccia, 2022, 2022a; Bontempi and Coccia, 2021; Calabrese et al., 2005; Coccia, 2004, 2005, 2008, 2008a, 2009, 2009a, 2010, 2010a, 2010b, 2012, 2012a, 2012b, 2014, 2014a, 2014b, 2014c, 2014d, 2016, 2016a, 2016b, 2016, 2017, 2017a, 2017b, 2017c, 2017d, 2017e, 2018, 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2018g, 2019, 2019a, 2020, 2020a, 2020b, 2020c, 2020d, 2020e, 2021, 201a, 2021b, 2022, 2022a, 2022b, 2022b, 2022c, 2022d, 2022e, 2022f, 2022g, 2023, Coccia and Benati, 2018, 2018a; Coccia et al., 2012, 2015, 2021, 2022; Coccia and Finardi, 2013; Coccia and Rolfo, 2009; Coccia and Watts, 2020; Magazzino et al., 2022.

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