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Innovation Failure: Typologies for appropriate R&D management

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Abstract. In markets having innovation-based competition and market turbulence, one of the fundamental problems is the high risk of failure in new innovation projects that generates negative effects on firm performance and related competitive advantage. In the field of strategic and innovation management, a vital aspect is the categorization and explanation of different failure types in innovation model and how their role can slow down or spur technological advances. The study confronts this problem here by developing a taxonomy to categorize different failures in innovation projects for technology analysis of the stages and sources of innovation failures in order to sustain strategic management to improve organizational processes in goal setting and achieving. The development of this framework is due to the lack in current literature of the innovation management of a categorization that describes the different typologies of failure in innovation projects that occur in the model of innovation. This theoretical gap generates difficulties both to communicate the specific types of innovation failure and provide fruitful feedbacks for improving strategic change in markets. Three basic types of failure in innovation projects are proposed: a) achieving-goal failure; b) planning process failure; c) execution failure. Case study research verifies proposed taxonomy in practical contexts, revealing that pharmaceutical sector is prone mainly to achieving-goal failure in innovation projects, whereas aerospace and aircraft industries are affected mainly by planning process and/or execution failure in innovative projects. This study conceives that proposed taxonomy can be used to: (1) describe what categories of failure are in-process and which are out-of-process in innovation model designed, and (2) detect the pivot stage in which failure in innovation project can origin to understand potential and current sources. The failure of innovation projects reveals the temporary bounded rationality and limits of people and organizations to solve problems in complex environments. Hence, this study seeks to provide a general theoretical framework, supported by a case study research, which may guide R&D managers, designers, analysts, etc. when a failure occurs in innovation processes to strengthen strategic management with best practices on how to better direct organizational efforts to manage failures properly, by reducing negative effects and improving the re-design of new goal-setting directed to maintain the strategies of firm in the right direction to pursuing competitive advantage in turbulent markets.
Keywords. Innovation Failure, Failure Analysis, Innovation project, Innovation Design, Goal Failure, Monitoring, R&D Management, Task Choice, Failure Management, Organizational learning..
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1. Introduction

Goal-setting is one of the fundamental aspects in strategic management to increase firm performance, 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 has a high probability and can generate negative consequences on firm, such as wasted investment, missed commercial opportunities for large firms and for small enterprises a goal-failure can also mine the future of the business in markets (Forsman, 2021; Taylor, 2021). Studies show that failing high and specific goals can be damaging for organizational behaviour and outcomes of firm in markets and management has to consider detrimental effects on organization and human resources when sets high and risky achieving-goal up in projects of innovation (Höpfner & Keith, 2021).

The vast literature on these topics analyzes different aspects. Starbuck & Hedberg (2001) examine the effects of successes and failures on organizational learning and technological development considering a partnership between firms. Cannon & 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 of organizational and managerial practices and in the presence of a failure, this event has to be the first stage to analyze sources and foster learning processes to support next goals in challenging projects (Coccia, 2012, 2017; Denrell, 2003; Desai, 2015; Savino *et al.,* 2017). Danneels & Vestal (2020) suggest two organizational approaches to failure analysis and treatment in organizations: normalizing failure (i.e., accept the failure as a necessary aspect of the innovation process) and analyzing failure (i.e., purposeful actions to analyze failure and related factors, and convert failure experiences into learning processes that increase organizational knowledge to achieve next strategic goals). They reveal that a normalizing approach does not improve the product innovation of firms, whereas the approach of in-depth analysis of project failure (e.g., by using Fault Tree Analysis in which an undesired state of a system is examined in organization or innovation process; Ericson, 1999, Larsen, 1974; Ruijters & Stoelinga, 2014) tends to create new products when it is associated with work involvement and constructive criticism. 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. The goal-failure in organizational behaviour can be an inevitable event of market turbulence but it can also generate positive effects for future achieving-goal and firm performance. In this context, Edmondson (2011) categorizes failures in three types, given by: a) preventable failures in predictable operations, leading to deviations from specifications in organization; b) unavoidable failures in firm, generated by a combination of elements; and c) intelligent failures of little entity that provide usefulness information for improving organization and managerial behaviour in markets. The approach of managers is that a soft stance towards goal-failure can reduce motivation and lead to laxness in human resources, whereas a critical analysis of failure sources can foster the grasp of factors to take advantage of new opportunities. Eggers (2012) analyzes knowledge creation in organizations by investing in a losing technology. The findings reveal the positive learning effects from losing technologies for the development of inter-related technologies (cf., Coccia & Watts, 2020): for instance, firm can use the experience of failure to update their expectations and choose less risky options in industry or to enter in markets after a reduction of technological and environmental uncertainty to benefit of learning advantages (Fleming, 2001). Ferreira *et al.* (2020) show the main role of experience and external knowledge provided by failures to support new innovative projects having lower probability of failure and higher effectiveness for firm performance and related competitive advantage. Velikova *et al.* (2018) argue that driving factors of failures can be due to poor management, cost and time overruns, human error in design and implementation of new projects, etc. (cf., Reason, 2000). Velikova *et al.* (2018) also suggest a taxonomy of failure that distinguishes levels and relationships between failures, and fosters the exploration of alternative paths to escape from well-known or rare factors of failure. The failure taxonomy proposed by Velikova *et al.* (2018) can identify risks of project development, commercial threats, etc. in order to improve communication and learning processes that minimize economic losses. Young (2019) analyzes scholarships for medical education and suggests three forms of failure: a) innovation-driven failure; b) discovery-oriented failure and c) serendipitous failure: occurrence of the unexpected. Magazzini *et al.* (2012) analyze the flops of product development in pharmaceutical industry and show that specialized firms occurring in failures have a higher frequency of citations than firms having a vast portfolio of projects. Instead, 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 pathways and also of partnership. Rhaiem & Amara (2019) suggest a framework of learning from innovation failures based on main phenomenon, explanatory variables of other phenomena, and mediating variables. Dana *et al.* (2021) argue that a lot of failure in innovation projects are often neglected, leading to a loss of knowledge for improving learning processes and applying corrective actions to achieve new opportunities in markets (cf., Mattarelli *et al.*, 2022; Gioia & Chittipeddi, 1991; Välikangas *et al.*, 2009).

Currently, the literature of innovation management, just mentioned, lacks any specific taxonomy to describe the differences pertaining to failures that occur in the model of innovation. This gap makes it difficult to communicate and focus on specific types of failure, analyze sources and apply appropriate solutions. The *principal goal* of the study here is to propose a new framework of concepts and a taxonomy that clarify in which stage an innovation can mainly fail between different sectors. Multiple-case study research verifies proposed taxonomy of innovation failure in pharmaceutical, aircraft and aerospace sectors characterized by more than 80% of failure in R&D projects. Suggested taxonomy of innovation failure here is a tool to 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 innovation failure for appropriate actions of problem solving. In fact, proposed theory and taxonomy here facilitate the differentiation of main types in innovation failure and increase the specificity in organizational communication to change current modes of cognition and action in order to take advantage of next opportunities or to face consequential threats leading to 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 of innovation occurs, to manage properly failures and support organizational and managerial behaviour of firms towards the right direction to achieve designed goals and sustain competitive advantage in turbulent markets.

2. Classification of failure in innovation projects

2.1. Basic concepts and relations for a theoretical framework of innovation failures

Failures of innovation projects occur in organizational contexts, such as firms, research labs, universities, international institutions, etc. An organization is a purposeful system that contains purposeful elements which have a common purpose to pursue with its human and economic resources (cf., Ackoff, 1971; Churchman, 1968). Organizations develop and apply strategies and planning actions to generate innovations (new things and new ways of doing things that are transformed into usable products and processes in markets; Coccia, 2021) directed to achieve goals and sustain a competitive advantage.

Strategy is the set of choices and actions, coordinated and coherent, in order to achieve a predetermined goal in a specified period (Simon, 1993). Strategies assemble projects, programs and plans.

Project is a process of planning, controlling and managing a set of resources to achieve a given objective, with a predetermined budget and within a predetermined period.

Program is a detailed statement of what an organization want to do, of the objectives aim at and of the means by which you intend to achieve them with a specific organizational behaviour.

Plan is a detailed list of modes of cognition and action necessary to achieve the objectives, using efficiently and rationally the organizational means and resources in a given period.

Organizational strategies, based on projects, programs and plans, can be directed to generate innovations, but they can also fail.

Failure is a complex concept that dissecting it, it includes elements of different intensity, given in increasing order by:

- *Fault* (*flt*) is caused by the lack or scarcity of scientific, technical and physical elements, and misleading modes of cognition and action that cause, with other elements, 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:

Let *flt*1=fault 1, *flt*i=fault i, ..., *flt*n=fault n ⇒ Error (*errj*) ={ *flt*1, *flt*2, ..., *flt* n}, $errj = \sum_{i=1}^{n} flt_i$

- *Failure* (*F*) is caused by a set of errors that leads to a deviation of the system from its main objectives;

Let *err*1, *err*2, ..., *err* j, ..., *err* m, *error for j=1*, ..., m ⇒
⇒Failure = { *err*1, *err*2, ..., *err*j, ...,*err* m}, $F = \sum_{j=1}^{m} err_j$

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 & Smith, 2020; Cannon & Edmondson, 2005).

Failure can be total and partial one.

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 = $\{err_1, err_2, \ldots, err_j, \ldots, err_m\} = \sum_{j=1}^{m} err_j$

Partial Failure is the non-achievement of circumscribed and specific objective, for some errors, in the overall design of main goal: Partial Failure = $\{err_1, err_2, \ldots, err_j, \ldots, err_{m-1}\} = \sum_{j=1}^{m-1} err_j$

Remarks. Total failure has a disruptive effect on overall system (project, organization, etc.), whereas partial failure can generate different effects on system, ranging from low, moderate, high and very high level (Figure 1).

Negative Effects					*None*	*Positive Effects*
–					0	+
Destructive Effects on System	*Very High Effects on System*	*High Effects on System*	*Moderate Effects on System*	*Low Effects on System*	Inconclusive Results for System	Success of system for achievement of the principal goal
Total Failure	**Partial Failure**					

Figure 1. *Different effects of partial and total failure in projects*

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., $S=F^C$). The space of events can include Failure (F), Success (S) 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.

Properties of failure can be systematized as follows:

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

2.2. Proposed taxonomy of failures of innovation projects

In order to classify the failure of innovation projects, the study considers a basic model of innovation based on market pull and/or technology push drivers (shown in Fig. 4). Model by Dodgson & Rothwell (1995) is adapted to make delineating categories of failure in innovation projects more straightforward. Organization applies this model in an attempt to achieve the designed goal of a new innovation. Expectation is that the strategic model develops a successful innovation. The phases of the model of innovation can be systematized in three main stages: setting-goals, planning and development, and execution/implementation (Figure 2, first line).

Figure 2. *Model and stages of innovation development with technology push and market pull drivers.*

The failures in the development of innovation can be categorized:

In-process failures of innovation and *Out-of-process failures of innovation* (Figure 3).

- *In-process failures of innovation* (referring to errors in the process to achieve the designed goals of a new innovation). The in-process failures of innovation are caused by faults and errors in the project that reduce the achievement of effective results.

The in-process failures of innovation projects can be of three main types, each in a specific phase where a set of errors can occur (Figure 3):

- failure in settings and achieving objectives of innovation project
- failure in planning and development of innovation project
- failure in execution of innovation project

- *Out-of-process failures of innovation* are caused by exogenous factors leading to flops, such as market change, environmental change, new factors, evolutionary dynamics of events, etc.

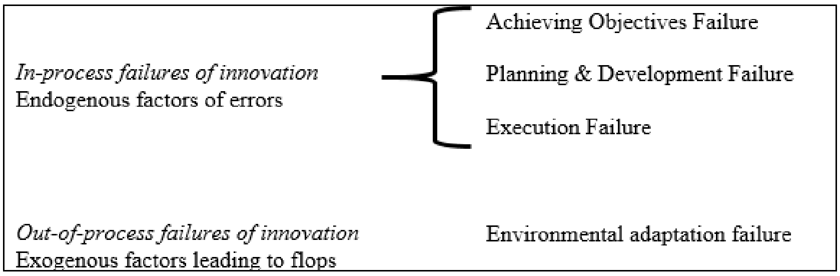

Figure 3. *Taxonomy of Failures of innovation projects*

 Achieving-goal failure: when an organization has a clear goal and is not achieved.

The first typology of failure in the model of innovation is related to setting-goal class and its achievement. The innovation failure in achieving-goal class is when the organization does not know what to do to make effective changes in the R&D process and related dynamic capabilities (Teece *et al.,* 1997) to generate a functional innovation in market. In short, if the organization has a clear goal in innovation strategy and is not achieved, or partially achieved, there is a total or partial *achieving-goal failure*. If organization has not a clear goal, the failure is not a failure in setting and achieving goal.

Example

First case. Development of innovative drugs has a high risk and about the 90% of projects fails during the clinical trial phases (Sun *et al.,* 2022).

Johnson & Johnson with Ad26.Mos4.HIV vaccine had the goal to protect people at risk of infection from the HIV (human immunodeficiency virus) that attacks the body's immune system and leads to AIDS (acquired immunodeficiency syndrome). In 2020, clinical trial of this type of vaccine failed (Taylor, 2022). Efficacy was about 25% after two years' follow-up, and as a consequence the goal is failed and innovation project is dismissed (Cohen, 2020; Harris, 2022).

Second case. Tocilizumab is a monoclonal antibody that inhibits the Interleukin-6 receptor associated with high inflammatory response. In the presence of Coronavirus Disease 2019 (COVID-19: a contagious disease caused by a novel severe acute respiratory syndrome coronavirus 2,SARS-CoV-2), in a perspective of technological exaptation (Ardito *et al.,* 2021), Tocilizumab was applied with the goal of avoiding the death of people because of high levels of interleukin-6 generated by reaction to COVID-19 (WHO, 2022). However, this innovative drug in combination with oxygen, corticosteroids, and other medications has had a partial failure of goal because in the largest clinical trial (RECOVERY), tocilizumab did not reduce negative effects of a severe infection, though with mild COVID-19, it can reduce patients' time in hospital (Gupta & Leaf, 2021; Yang & Zhao, 2021).

Third case. Biogen (American multinational biotechnology company) endeavored to develop the anti-tau antibody gosuranemab drug—licensed from Bristol Myers Squibb in 2017— to treat Alzheimer's disease but it failed the phase 2 trial and was rapidly dismissed (Taylor *et al.,* 2022). The setback is associated with other failed trials involving drugs targeting tau, a protein that forms insoluble filaments and accumulate as neurofibrillary tangles in Alzheimer's disease patients and related tauopathies. The antibody gosuranemab was also ineffective in other trials for patients with progressive supranuclear palsy, a type of neurodegenerative disorder. In short, the goal of an innovative drug focused on Tau (the microtubule-associated protein) to treat Alzheimer's disease, with current evidence, is ineffective, leading to flop of designed goal (Teng *et al.,* 2022).

- *Planning and development failure in innovation project:* This failure is due to ineffective and inefficient plan in innovation development.

Planning of innovation development refers to moment to moment success in taking actions in the correct time and scheme, from starting to ending phase, to achieve the goal . Failures in this stage are due to making ineffective and inefficient plan: the failure is due to at simply making an incomplete and limited plan. This type of innovation failure is also due to a scenario that makes an organization not able to progress towards the designed goals because of a poor loadout (a set of resources and abilities chosen by the organization before embarking on a strategic project of innovation) or if innovation does not match the outlined design intent.

Example

An example is the drug Bintrafusp alfa by GlaxoSmithKline (GSK, British multinational pharmaceutical and biotechnology company), in agreement with healthcare company Merck, for treatments of solid tumors, such as non-small cell lung cancer (NSCLC) with high expression of the PD-L1 biomarker (Taylor, 2020). The R&D process of this innovative drug, in January 2021, shows problems in a trial, which enrolled patients with stage 4 of NSCLC, such that Bintrafusp drug failed to outperform Keytruda (another drug that may treat certain cancers by reinforcing immune system; Barlesi *et al.,* 2022). Hence, GSK did not succeed in the planned activity of developing and implementing this drug as anti-cancer treatment, because the drug did not advance sufficiently in pipeline, generating results lagging compared to other competitors that used alternative drugs (Taylor, 2020, 2021).

Another example is in the aerospace mission of Space Shuttle Challenger in 1986, when a malfunction in the spacecraft's O-rings—rubber seals that separated its rocket boosters—caused a fire to start that destabilized the boosters and destroyed the rocket itself. This is a combination of development failure and achieving-goal failure (Hogeback, 2023).

 Execution failure: when organization does not succeed in something they had planned to do.

Execution failure of innovative project is when an organization is not able to finalize the correct ending phase of innovation model.

Example

During liftoff of Space Shuttle Columbia in 2003, there is a breaking off of a piece of foam that was intended to absorb and insulate the fuel tank of the shuttle from heat and to stop ice from forming. After that space shuttle has successful done the innovative mission in space, when it attempted reentry in Earth to finalize and complete its mission, initial problem has created another one: gases and smoke entered the left wing through the hole and caused the wing to break off, leading to the disintegration of the shuttle totally (Hogeback, 2023).

- *Out-of-process failures* are due to exogenous factors to innovation project and/or organization (e.g., market changes, new events, etc.) that lead to flops. This type leads to an environmental adaptation failure of the system (e.g., organization).

Example

Monoclonal antibodies have been considered main therapeutic alternatives to treat COVID-19 patients having mild, moderate to severe symptoms. Some of them, such as bamlanivimab/etesevimab and Regeneron's casirivimab/imdevimab have been tested in clinical trials. Although experimentations have been applied appropriately, the exogenous factors given by the mutation of initial vital agent SARS-CoV-2 into the omicron variants and subvariants (BA.1, BA.2, BA.3, BA.4, and BA.5 and two subvariants of BA.5 given by BQ.1 and BQ.1.1) considerably reduced their efficacy, leading to failure as appropriate therapeutic treatments for COVID-19. Other monoclonal antibody trials also bring up problems of effective treatments for manifold external factors (Focosi *et al.*, 2022; Nagler *et al.*, 2022).

3. Case study research to substantiate the framework

3.1. Multiple-Case study

Proposed taxonomy of failure is verified with a case study research and examples that clarify the practical application in innovation projects. Multiple-case study research plays a main role to support the process of inducting theory in new topic areas (Eisenhardt, 1989). The proposed taxonomy here, supported with accurate study cases, can be valid and consistent because of the clear linkage with empirical evidence. The evidence with case study research here has independence from prior literature and is particularly well-suited to these research areas in which existing theory is scarce. Eisenhardt & Graebner (2007) argue that theory building based on case study research can create a strong connection from qualitative evidence to deductive research. The practical verification of the taxonomy of failure in innovation projects, showed in table 1, is based mainly on study cases from pharmaceutical sector where 90% of drug discovery and development fail (Sun *et al.,* 2022) and from aircraft and aerospace sectors that record a lot of flops (cf., Qin *et al.,* 2005; Celikmih *et al.,* 2000; Li & Hou, 2022; DeLucia *et al.,* 1989; Fernández *et al.,* 2022; Romanova *et al.,* 2013; Kaplan, 2022).

Information are based on secondary data that play a vital role in scientific research and evidence based on a case study research (Ansari *et al.,* 2016; Kozinets, 2002).

Table 1. *Verification of the taxonomy of innovative failure in practical examples*

Innovative products	Results	Types of failure	Consequences
Johnson & Johnson Ad26.Mos4.HIV vaccine in 2022 for HIV, a virus that attacks the body's immune system.	Efficacy in trial was about 25% after two years' follow-up: vaccine did not reduce transmission of HIV and failed principal goal. Trial dismissed (Taylor, 2022).	*In-process Failures:* Achieving-goal Failure	Technological change in vaccine development from adenoviral approach (of J&J's Ad26.Mos4.HIV vaccine) to mRNA techniques.
Merck & GSK Bintrafusp alfa drug for solid tumors in 2021-2022	This anti-cancer drug did not work in trials for non-small cell lung cancer, biliary tract cancer, etc. failing main goal (Taylor, 2022).	*In-process Failures:* Achieving-goal Failure	GSK firm returned rights to the drug to Merck corporate and it is no longer in the R&D project.
CureVac COVID-19 vaccine in 2022	This vaccine was found to offer a scarce 48% protective efficacy rate in phase 3 trial to face COVID-19, failing the goal (Taylor, 2022).	*In-process Failures:* Achieving-goal Failure	The firm CureVac N.V. withdrew authorization applications and joined with GSK corporate to develop second-generation of mRNA vaccines.
Biogen's gosuranemab for Alzheimer's disease in 2021	In trial, results showed clinical progression of dementia; the drug failed to top placebo and also failed across other trials including cognitive dysfunctions (Taylor, 2022).	*In-process Failures:* Achieving-goal Failure	Biogen firm has switched to develop other drugs.
Anti-COVID/19 drugs in 2022-2023	A lot of vaccines and monoclonal antibodies have experienced a reduction of effectiveness to cope with negative effects of COVID-19 because of emerging variants and sub-variants of the novel coronavirus.	*Out-of-process Failures*	Environmental change leading to strategic change
Boeing 737-MAX over 2018-2019	Boeing's 737-MAX aircraft was operational in 2016 but in 2018 some pilots had lost control of the aircraft because of the failure of a sensor and other technical problems of the aircraft's systems. This new aircraft showed problems with the aircraft's design and project development as a whole (Calleam, 2023).	*In-process Failures*: Planning & development failure	The worldwide fleet was dismissed.
STS-51-L: Space Shuttle *Challenger* in 1986	A malfunction in the spacecraft's O-rings—rubber seals that separated its rocket boosters—caused a fire to start that destabilized the boosters and destroyed the rocket itself during the take-off (Hogeback, 2023).	*In-process Failures*: Planning / execution failure	Temporary suspension of the space shuttle program

Soyuz 1: Parachute Failure in 1967	The Soyuz 1, the Soviets' first space vehicle, in 1967 intended to reach the Moon. In the space, a solar panel was malfunctioning, creating difficulties in controlling the vehicle. It was decided for a return to Earth. The parachutes on Soyuz 1 did not unfold correctly leading Soyuz 1 to crash into Earth (Hogeback, 2023).	*In-process Failures*: Execution Failure	Temporary suspension
STS-107: Space Shuttle *Columbia* in 2003	During liftoff of Space Shuttle Columbia, there is a breaking off of a piece of foam that was intended to absorb and insulate the fuel tank of the shuttle from heat and to stop ice from forming. When the Columbia attempted reentry in Earth, after its space mission was successful and complete, initial problem has created another one: gases and smoke entered the left wing through the hole and caused the wing to break off, leading to the total disintegration of the shuttle (Hogeback, 2023).	*In-process Failures*: Execution Failure	Temporary suspension
Europe's Vega C rocket in 2022	Europe's new Vega C rocket, with two satellites for Airbus' Pléiades Neo Earth-imaging constellation, in December 2022 because of problems in launcher, the rocket veered off course less than three minutes after launch, leading to a failure of mission and loss of two satellites. (Wall, 2022; cf., Jacklin, 2022).	*In-process Failures*: Planning failure Execution Failure	Temporary suspension

4. Discussion, theoretical and management implications

Failure is a set of errors that leads to a deviation of the process from its principal goal. The usefulness of the proposed taxonomy of failure in innovation projects is to detect the main stage in which an innovation project can fail to improve communication and strategic management in organizations. This classification can also improve our understanding of how projects of innovation flop in order to apply best practices to avoid bottlenecks in development process. Results of the taxonomy of failure in innovation projects applied in practical study cases suggest that in pharmaceutical sector, the failure in innovation projects is mainly of the type of goal failure, whereas in aircraft sector and space launch vehicle of space mission, the failure is mainly in the stage of process and execution of innovative projects (O'Hare, 2000; figure 4). In general, the failure in innovation projects depends on the specificity of project and sector in which it is developed and application of proposed taxonomy has to be appropriately contextualized to provide correct technology analyses for fruitful R&D management implications.

Setting-goals	Process planning	Execution and implementing actions
Pharmaceutical sector has experienced in innovation projects mainly a failure in achieving goals.	Space launch vehicle and aircraft sectors have mainly flopped in planning and execution phases.	

Figure 4. *Types of failure in innovation projects in pharmaceutical, space launch and aircraft sectors*

Results also show that for many projects, the types of innovation failure can lead to the end of the project, such as in pharmaceutical sector, the failure in trials of GSK-Merck Bintrafusp alfa drug for solid tumors leads GSK company to interrupt the agreement with Merck corporate for developing this drug, whereas in other cases the innovation failure leads to direct resources towards other goals, such as when CureVac vaccine failed to treat COVID-19, the German biopharmaceutical company CureVac has decided to joined with GlaxoSmithKline to develop second-generation of mRNA vaccines for new vital agents.

4.1. Implications of strategic management in failure of innovation projects

In the presence of failure in innovation projects, described in proposed taxonomy, organizations can apply two basic strategies:

Adaptation. Adaptiveness as strategy for innovation failure is the ability of an organization to modify itself or its environment when either has changed to the organization's disadvantage so as to regain, whenever possible, at least some of its lost efficiency and performance. In fact, if the failure of innovation has generated a change in the internal state of organization which reduces its efficiency in pursuing one or more of its goals in innovation projects, a managerial implication is that organization can react by changing its own state and/or that of its environment so as to increase its efficiency to achieve and sustain that goal or goals for next innovations (see example in Table 1, cf., Ackoff, 1971).

Hence, in the presence of an innovation failure (F) of achieving goal or out-of-the system type, 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 $\Leftrightarrow$ A(α,E)>A(β,E)

Learning. 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 & Frascheri, 2015). In particular, learning, because of an innovation failure in the process and/or execution stage, is directed to increase one's efficiency in the pursuit of new processes under current and potential unchanging conditions (Levinthal & March, 1993; Madsen & 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. Weick (1991) argues that organizational learning have mixed different concepts, such as change, learning, and adaption. In a perspective of strategic management for dealing with innovation failures, R&D managers and designers should consider learning as the: "the process within the organization by which knowledge about action-outcome relationships and the effect of the environment on these relationships is developed" (Duncan & Weiss 1979, p. 84, cf., Weick, 1991). Organizations, in the presence of failure in innovation projects, have to change routines to cope with environmental turbulence and the theory by Argyris (1976) proposes two learning approaches: organizational research and trial-and-error. Argyris (1976) argues that the sequence of trial-and-error approach in a process of innovation development can foster changes in the organizational behaviour directed to converging designed activities and learning processes to achieve expected results (cf., Nelson, 2008). In this context, Argyris (1976) suggests:

-- *single-loop learning* in which organizations detect deviations and change their actions to minimize the difference between expected and obtained results, maintaining the design intent and current routines in organization.

--*double-loop learning* leads to radical change in organizational and managerial behaviour.

All these vital aspects can support strategic management of organizations to dealt with innovation failure by applying learning processes that change routines to achieve new goals in innovation projects to take advantage of other opportunities .

Hence, innovation failure can improve strategic management and trigger positive effects in new R&D processes that can generate effective incremental and/or radical innovations driven 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 best practices of strategic management that create a new model of innovation that foster 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).

4.2. Theoretical implications of the failure in innovation projects

Findings of the study can provide theoretical implications, represented simply here by using set theory.

Properties:

- Error is caused by a set of faults:

Let *flt*1=fault 1, *flt*i=fault i, ..., *flt*n=fault n ⇒ Error (*errj*) ={ *flt*1, *flt*2, ..., *flt* n}, *errj* =$\sum_{i=1}^{n} flt_i$

- Failure (*F*) is caused by a set of errors:

Let *err*1, *err*2, ..., *err* j, ..., *err* m, *error for j=1*, ..., m ⇒

⇒Failure = { *err*1, *err*2, ..., *err*j, ...,*err* m}, $F = \sum_{j=1}^{m} err_j$

- Total Failure = { *err*1, *err*2, ..., *err* j, ..., *err* m}=$\sum_{j=1}^{m} err_j$
- Partial Failure = { *err*1, *err*2, ..., *err* j, ..., *err* m–1 }=$\sum_{j=1}^{m-1} err_j$
- *Inclusion*: flt ⊆ err ⊆ F
- Error condition: flt ⇒ err (fault is a necessary but not sufficient condition for an error in a system)
- Failure condition: err⇒ F (error is a necessary but not sufficient condition for failure in a system)
- 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.
- Innovation failures can be of three types: goal failure, process failure and execution failure.

- 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. Condition of F (Failure): Organization A can face:

2a. δ-innovation fails for predictable facts, events, problems, adjustable in R&D process

2b. δ-innovation fails for unexpected facts, events, problems, adjustable in R&D process

2c. δ-innovation fails for predictable facts, events, problems, unsolvable in R&D process

2d. δ-innovation fails for unexpected facts, events, problems, unsolvable in R&D process

3. Condition of δ-failure. Conditions 2a and 2b leads to *non*-F, Conditions 2c and 2d leads to A's δ-innovation failure F (Figure 5).

		EVENTS	
		Predictable	Unexpected
INTERVENTIONS	Adjustable	Non-Failure	Non-Failure
	Unsolvable	Failure	Failure

Figure 5. *Matrix of failure and non-failure in innovation projects*

- Type of innovation failure is affected by specific innovative activities and by sector in which is developed.
- In the presence of a failure (F) of achieving goal or out-of-the system failure, 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: α is better adapted to innovation F than β in E ⇔ A(α,E)>A(β,E)

5. Conclusions and limitation of the study

Innovation failures and errors are basic elements of scientific and technological progress (Barwich, 2019; Borycki, 2013). Since organizational and managerial behaviour vary to different types of innovation failures, it is important to discriminate different types of innovation failures for improving upstream design and downstream applications. In fact, the understanding and systematization of innovation failures are critical aspects to spur strategic management towards improved R&D processes directed to new innovations. This study here shows that the categorization of how and in which stage innovation projects fail is a critical aspect in innovation management to identify the best innovation strategy for new activities. This paper defines and categorizes the failure in innovation projects in three main types, -- the achieving-goal failure, design, development and execution failure,-- which lead to a deviation from expected results. If the taxonomy shows that the failure is in a specific stage of innovation development, it is possible to use this information to guide organizational changes in order to avoid a lot of similar failures that can become frustrating and detrimental for further R&D projects, organizational motivation and firm performance. Hence, in science is basic to explain different failure types and their accurate role in the R&D process because they can improve strategic management and induce technological advances with new directions. In fact, innovation failure has a positive aspect that supports new business models in organizations directed to scientific and technological development (Barwich, 2019; Sosna *et al.,* 2010). This study about failures (given by a set of errors and faults) clarifies different types of failure in innovation projects that show the temporary bounded rationality and limits in organizational behaviour, such as failures described in drug development to treat Alzheimer's disease and other cognitive disorders, focused on tau protein, (Taylor, 2021) or new target therapies to treat mutant lung cancer (Coccia, 2012, 2016, 2017), etc. Different types of failure in innovation projects boost the organization to extend the perspectives in the process of R&D by exploring alternative technological pathways and/or new directions of investigation to solve specific problems and advance science and technology. In short, heterogenous typologies of failures in innovative projects (e.g., in drug discovery processes, space missions, etc.) induce organization to experiment alternative paths and new modes of action and cognition to solve problems in order to cope with unforeseen aspects and environmental changes.

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

(1) describe what categories of failures are in-process and which are out-of-process in innovation model designed, and

(2) discriminate different types of failure in innovation projects per various industries to better understand which are problematic phases in sectoral patterns that should be avoided and/or improved in R&D process to support firm performance and related competitive advantage.

Taxonomy of innovation failure in practical contexts is important to assess where and why the innovation projects fail in order to avoid, ex-ante, specific classes of failures in R&D process considering the specificity of projects and industry in which firms operate. The analysis of a R&D project using the proposed taxonomy of failure, associated with other approaches, such as Fault Tree Analysis (Hixenbaugh, 1968; Vesely *et al.,* 1981, 2002), can also offer criticism of the overall development process of innovation and in deciding which design changes are appropriate for new innovation models given organization, industry and market-target. In fact, flops emerging in the R&D and implementation, conveniently categorized, can provide fruitful feedbacks to organizations to adapt and/or learn improving strategic management to minimize errors in new R&D plans.

Overall, then, organizations can fail in a variety of ways and phases while developing innovations (McGrath, 1999). Failure is part of the innovation process and is even expected to occur naturally in the phases of R&D (Petroski, 1985). Appropriate solutions to current and potential failures of innovation can be better guided with a taxonomy and this is why we have introduced accurate terms that clearly differentiate the types of failures expected and unexpected in different phases of the R&D process (Lampel *et al.,* 2009; Pangione, 2020).

Although the proposed taxonomy is useful for strategic management in innovation failure, it is important to be aware of the limitations. First, some failures are borderline between the proposed typologies and they can be a combination of them. As consequences a better and extended categorization should be pursued in future studies. Second, the use of taxonomy of failures in the initial phases of innovation design can avoid some errors or faults and direct the projects in some directions, discarding interesting insights from other directions. It is important to be flexible in using the taxonomy of failure in innovation projects to consider all possible technical alternatives for improving R&D and achieving the designed goals of projects. Third, this study proposes a taxonomy and evidence based on a case study research but next step should be a data-driven evidence to confirm results and prediction of the proposed theoretical framework here.

Hence, types of innovation failure have to be known, *ex-ante*, to be, when occur, accurately categorized for appropriate communication and application of best-practices of strategic management to minimize undesirable effects in organizations and direct resources towards effective directions. For organizations, the understanding of goal-failure and of other types is as important as goal setting and achieving, for improving R&D process that supports firm performance and competitive advantage. Overall, then, proposed taxonomy of failure in innovation projects here does not represent specific classes of failure but general aspects in the vast spectrum of R&D projects across different sectors. Without taxonomies and general framework, like this, R&D managers have to work harder and the chances for finding correct solutions for success can reduce (cf., Casey, 2105; Xhignesse, 2020). Hence, this study contributes to theory and innovation management to elucidate different types of failures that can generate consequences on organizational behaviour, especially when goals are failed consecutively and the organization has no resources, know-how and dynamic capabilities to counteract the negative effects with strategies of learning and adaptation to new contexts.

To conclude, organizations, to achieve and sustain competitive advantage in turbulent markets with new innovations have to know types and characteristics of failures in R&D models.

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