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# A correlated redefinition of the concept of resilience in a production system

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**Abstract.** There are many definitions of resilience. Their common core is that it is a response to unexpected or unforeseen changes and disturbances, and a capacity to adapt and respond to these changes. In the literature, many different concepts were identified to accompany resilience and help define or measure a system's resilience. These include flexibility, vulnerability, rapidity and robustness. However, these concepts are sometimes used interchangeably with resilience as there is a lack of clarification among them. In addition, the role of "lessons learnt" and "learning" after a disruption is somehow neglected in existing studies of resilience and system performance. This article aims to position resilience regarding these concepts, taking into account the system's experience after several disturbances. Schematic presentation of resilience-related concepts such as flexibility, rapidity, vulnerability and robustness are proposed. Additionally, an updated definition of resilience in a production system while considering the correlated concepts like vulnerability, robustness, flexibility, rapidity is proposed.

**Keywords:** Resilience, Flexibility, Robustness, Disruption, System Performance, Manufacturing, Production System.

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## 1 Introduction

Resilience as a concept has been widely discussed in various fields and disciplines. Different definitions have been offered for each of the disciplines, however, they all share a common point: resilience enables a response to unexpected or unforeseen changes and disruptions. It is an ability to adapt and respond to such changes. [1] has introduced 14 different definitions in different fields like engineering, socio-ecological systems, ecological systems, physical systems, organisational, individual, psychology and disaster management. However, they have mentioned that, in each of these contexts, resilience can be summarised as "the capability and ability of an element to return to a stable state after a disruption."

First popularised by [2], resilience is the ability of natural systems to deal with change. This definition has been used as the foundation of many works afterwards [1]. [3] defined resilience as the "system's ability to limit the likelihood of shocks, absorb shocks with a rapid recovery of performance, and recover rapidly from aftershocks or restore performance to normal conditions". In the same study, they discussed that resilience will address different objectives ranging from risk reduction to reducing the impact of a disturbance, notably on the time needed for a system to return to a "normal" state. [4] showed that resilience mostly leans toward two different approaches: engineering resilience and ecological resilience. The first type considers resilience as the speed of return to the "steady" state following a disruption; therefore, resilience is concentrated on the efficiency of a set of functions. The second type defines resilience as the "magnitude of disturbance that can be absorbed before the system restructures"; here, resilience is concentrated on the survival of discrete functions. Furthermore, [5] linked resilience to the response of a system, notably a production system, in time of failure and how the system moves up from failure to success. Not very far from that study, [6] showed that resilience is the ability of the production system to recover and resume operations following some types of failures. These failures can be of different types like: user dissatisfaction (for example when the demand quantity is not

met), insufficient or unavailable resources, partially damaged infrastructure, or the presence of any nuisance in the production system that can disturb the system, the human and/or the environment. In [7], resilience comes with three different capabilities, namely absorptive capacity, adaptive capacity and restorative capacity. Absorptive capacity assesses how well a system can absorb shocks and minimise their consequences. Adaptive capacity refers to the ability of the system to modify its operations proactively or during disruption. And finally, retroactive capacity is the system's ability to return rapidly to normal, or even enhance reliability after facing a disruption or an adverse event.

These points align with the aspects of resilience outlined by [1], which encompass readiness and preparedness, response and adaptation, and recovery or adjustment. Despite efforts by various authors to address these broad areas comprehensively within a resilience-focused framework, each aspect has received limited systematic attention and empirical study individually. Consequently, a diverse range of literature has emerged on this topic.

Looking through all definitions, resilience can be seen as an essential ability of organizations to cope with the various disturbances encountered to ensure their efficiency in the context of an increasingly complex and evolving industrial environment. In addition, resilience as a key concept also appears in interdisciplinary areas concerned with complex systems, such as enterprises, critical infrastructure systems and ecosystems [8].

The concept of resilience is largely connected with different other concepts like robustness, flexibility, and vulnerability. As far as the literature is concerned, resilience has been discussed considering one disruption and the consequent system performance, however the role of learning and updated processes after the first disruption is hardly investigated. In [9], resilience principles are mentioned as anticipation of a disturbance, resistance by adapting and recovery by regaining the state of before the disturbance. It will raise a new horizon to the concept of resilience, to compare the state after the disruption to the one before: whether the processes after the disturbance are new, updated or the same state as before.

This article focuses on positioning resilience and the connected concepts during different disruptions to come up with an updated-correlated definition. To do so, the article is organised to discuss the related concepts in section 2. Afterwards, the resilience and system performance will be presented in section 3. Section 4 and 5, will focus on the objectives of the research, namely designing graphs concerning resilience and the related concepts, following a redefinition of resilience. All the findings then are synthesized in section 6.

## **2 Related concepts**

Many different concepts have been identified to accompany resilience in the literature which help define or measure the resilience of a system. Among all, the following concepts are considered for this study:

- **Robustness:** strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function [3];
- **Flexibility:** Flexibility can be defined as the ability of a system to adapt to the changing requirements of its environment and its stakeholders with minimum time and effort [8];
- **Rapidity:** the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption [3];
- **Vulnerability:** A state in which a system is sensitive to stress conditions (i.e. no more robust) and is subject to the risk of rupture or failure [10,11].

However, the relationship between these characteristics and resilience seems to be missing from the literature.

### 3 System performance and resilience

System's performance evolution over time and in times of disruption has been used to show the concept of resilience in the literature (see Fig. 1). In the figure, the system's performance is compared in the three phases of resilience:

- 1) **In operation:** nominal operation before disruption;
- 2) **Response:** performance loss after disruption and
- 3) **Recovery:** return to a steady state. Response and recovery require complementary capabilities named absorptive and restorative [12].

After the recovery, the system will continue with a performance (a) worse than, (b) the same as or (c) better than its performance before the disruption, which refers the evolution of the system after a disruption. Additionally, the vulnerability zone is shown as an area of performance, where the system survival is at risk. This area changes dynamically as time and performance evolve based on the impact and likelihood of a disruption. More severe impacts and more probable shocks make the system more vulnerable and more at risk of failure [13].

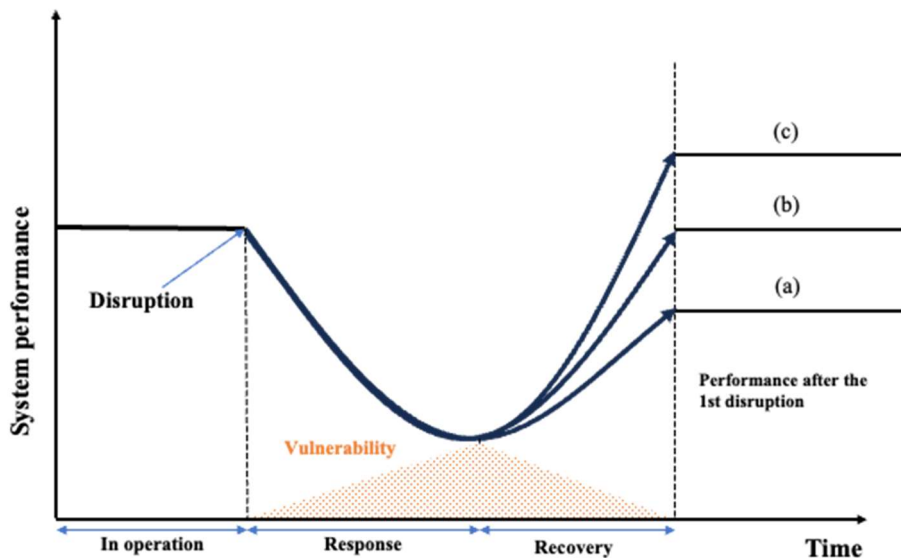


Fig. 1. Resilience and the performance of the system inspired by [12]

Fig. 1. proposes a traditional representation of the resilience. Although the "ability to resist" is stressed, the depicted behaviour can be closer to the concept of flexibility rather than resilience. To that point, the objectives of the study in hand will be twofold:

- O<sub>1</sub>: Define the resilience graph, taking into account the system's experience after several disturbance
- O<sub>2</sub>: Introduce a schematic presentation of resilience-related concepts such as flexibility, rapidity, and robustness.

### 4 O<sub>1</sub>: System's experience and resilience after several disturbances

In Fig. 1, the system performance and resilience were demonstrated when the system faced a disruption. However, as discussed above, it is important to consider the role of "learning" in the system performance while facing disruptions. Therefore, Fig. 2 tries to illustrate resilience and system performance while facing several disruptions.

#### 4.1 The first disruption

As shown in Fig. 2, the system's performance will face different phases before, during and after a disruption. Before the disruption, the system is "In Operation"; the moment the system encounters a disturbance, it makes a response to this event, and the performance drops until it can start to recover. After recovery, the system needs some time to stabilize and get "in operation" again.

However, if the system can keep its performance above the vulnerability zone during the "response phase", it can be interpreted that the system has survived the disruption; therefore, the performance curve starts to elevate. Afterwards, the system starts to stabilize with a performance better ((c) best scenario), worse ((a) worst scenario) or the same (b) as the performance before the disruption.

In Fig. 2, for the sake of clarity, only one scenario is represented after stabilization, scenario (c) is chosen.

#### 4.2 The second disruption

When a second disruption occurs, its magnitude can differ from the first one. In Fig. 2, this disturbance is equivalent than the first disruption.

The system performance drops again after facing the second disruption, but it has learned and gained experience from the reaction to the previous disruption. Consequently, the system responds faster and better to the disruption, the performance does not go as low as the first time and the system starts stabilizing its performance more rapidly. As mentioned in [13], vulnerability is highest when both likelihood and the impact of disruption are high. After the first disruption, thanks to the learning procedure that comes up with new and/or updated processes, the consequences of the disruption gets lighter and the systems is less prone to the risk, therefore the vulnerability is reduced and the system will survive with higher probabilities.

In Fig. 2, for the sake of clarity, only the scenario with the same performance (b) is represented.

#### 4.3 The third disruption

When a third disruption occurs, its magnitude can differ from the first and second ones. For the sake of clarity of the illustration, in Fig. 2, a bigger disruption than the previous ones are represented.

As shown in the figure, when the system encounters a bigger shock, although the performance drops lower, it will not break and it will enter the recovery phase, thanks to the experience the system has earned. As the system has already learned, the vulnerability is even smaller than the first disruption. Consequently, the system starts to recover and stabilizes its performance.

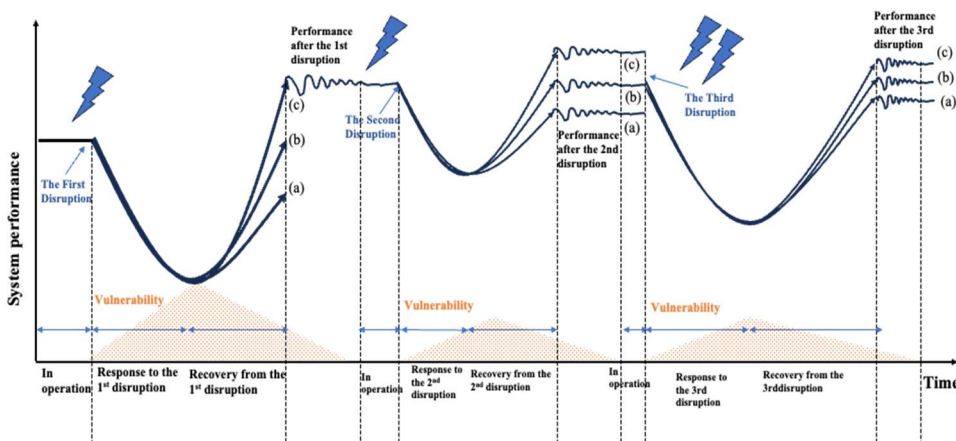


Fig. 2. Resilience and the system performance after the first disruption

## 5 O<sub>2</sub>: Resilience and related concepts after the first disruption

In the following section, the two connected concepts with resilience, flexibility and robustness, are studied concerning the system performance while facing several disruptions. For each of the concepts a schematic presentation is prepared (see Fig. 3 and Fig. 4).

The terms presented in the following figures regarding system performance while having disruptions are equal to the ones used in Fig. 1 and Fig. 2. However, based on [9], three modes are added to the state of a system while facing a disruption: Normal mode, Degraded mode and critical mode. Normal mode (NM) is the mode in which the system operates without the occurrence of events that can interrupt its performance. Degraded mode (DM) is the mode the system performs under latent conditions and finally, Critical mode (CM) is the mode in which the system is under disruption and its survival is at risk.

### 5.1 Resilience and flexibility

Flexibility has proven to be an imminent characteristic of resilience in the literature. [8] indicates that a system's adaptive capacity during disruptions can be enhanced by integrating flexibility into its design, planning, and construction. [14] asserts that resilience in a system is its capacity to recover from disruptions by building redundancy and flexibility. [15] relates flexibility to bending or pushing a system without breaking it and connects flexibility to adaptability, openness and adjustability of a system. Meanwhile, [16] characterizes flexibility as the ability to adapt by leveraging efficiency, responsiveness, versatility, and robustness. [17] links flexibility to agility and adaptability, proposing that flexibility represents a system's capability to swiftly adapt to evolving environments.

Fig. 3 depicts the flexibility and the performance of the system while facing several disruptions. As discussed above, the first and the second disruptions are considered to be equally strong, while the third one can be of a bigger magnitude. By definition, flexibility is the capacity of the system to adapt to changing environment in the minimum time and with minimum effort. Unlike resilience, the system performance does not make drastic changes in terms of flexibility while facing disruptions, the most important objective is to recover and stabilize in the short time possible. Therefore, flexibility will not be only bound to time, it will be also effort-dependent. Thanks to the updated and/or new processes the system gets after the first disruption, the system demonstrates increased flexibility after the second disruption, and it begins to stabilize in a shorter duration compared to the first disruption. However, the system requires a longer duration and greater effort to overcome a larger shock during the third disruption. This indicates a reduction in the system's flexibility, although it ensures survival. Therefore, after the first disruption the system passes from normal mode to critical and then to a degraded mode. However, after the second disruption, the system bounces between normal and degraded mode and will not experience a critical mode.

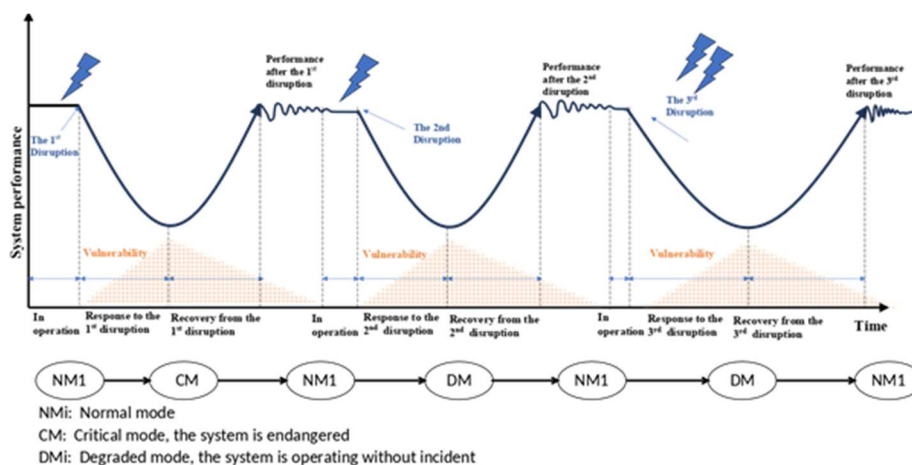


Fig. 3. Flexibility and system performance after the first disruption

## 5.2 Resilience and robustness

[3] characterizes resilience with four different properties (the 4 R's of resilience): robustness, redundancy, resourcefulness and rapidity. In that context, they define robustness as "strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function". They identify "robustness" and "rapidity" as the two "ends" for resilience meaning the ultimate and desired goal of the resilience system significantly influencing decision-makers and stakeholders. The other two, redundancy and resourcefulness are considered "resilience measures" used to improve resilience. As mentioned above [14] has related several contributory factors for resilience like flexibility. Robustness is another factor they believe has an overlapping quality with resilience and they define a robust system as "a system that can maintain operational performance despite parametric disturbance". [11] define robustness as the ability of the system to preserve its functionality under conditions that deviate from their normal state while resilience is the ability of the system to withstand changes. However, they used both concepts of resilience and robustness as the system's abilities to cope with a disturbance in a system.

Fig. 4 schematically discussing the robustness of a system while it faces several disruptions. By definition, robustness is the capacity of the system to withstand a level of stress without losing or degrading of functions. Unlike flexibility, robustness is concerned with fixed processes and a given level of stress and it will change behaviour with the magnitude of a disruption. Therefore, while having the same level of disruption, the system continues to perform and will not go down. However, in case the system receives a bigger shock, although learning happens in the system after the first disruption, the performance of the system will fall down into the vulnerability zone which most probably would lead to a breakdown in the system.

Unlike flexibility, the system will bounce between normal mode and critical mode as the vulnerability of the system is highly dependent on the amplitude of the disruption while looking at robustness.

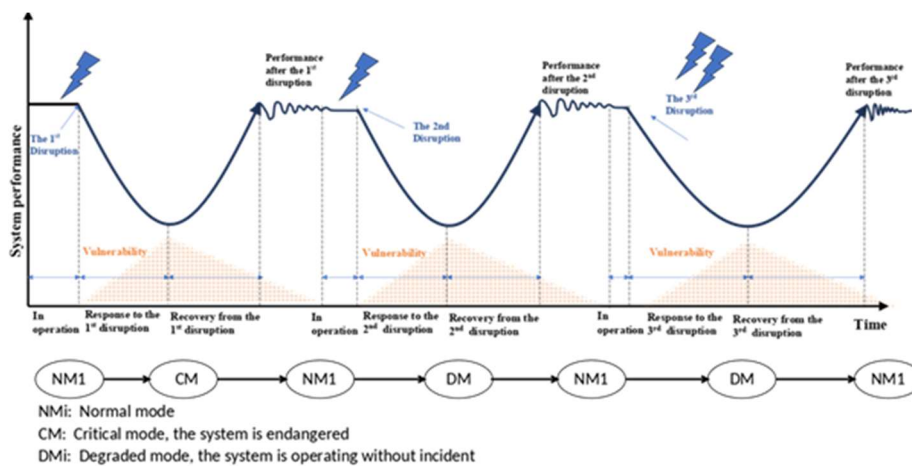


Fig. 4. Robustness and system performance after the first disruption

### 5.3 Positioning of the different concepts

Considering all the concepts above, Fig. 5 represents the resilience of a system while facing several disruptions with different magnitudes. Additionally, the above-mentioned concepts are positioned concerning the system's performance. To summarize, an ideal system, will learn from a disruption. When a first disruption happens, the system is the most vulnerable, the performance might drop drastically and it might take a long for the system to stabilize its performance. The system's flexibility will assist the system adapt to the changing requirements no matter how big the disruption is. However, flexibility is not bound to the time it takes for the system to stabilize after a disturbance. On the other side, robustness will be performance-based and also dependent on the magnitude of the disruption. The rapidity of the system to recover from a disruption will also change based on the shock, but will also affect the experience of the system after the first disruption: the system will learn and recover faster.

After each disruption, the system evolves, it means that the processes are whether updated or newer, and this will help the system to reduce the consequences and the impacts of each disruption. The lower the impacts get, the less vulnerable the system is. Therefore, after each disruption, the system will elevate its chances of survival. On the other side, based on [13], reducing vulnerability leads to a reduction of the likelihood of a disruption and will increase the ability of the system to bounce back from the disruption, which means higher resilience and more flexibility for the system.

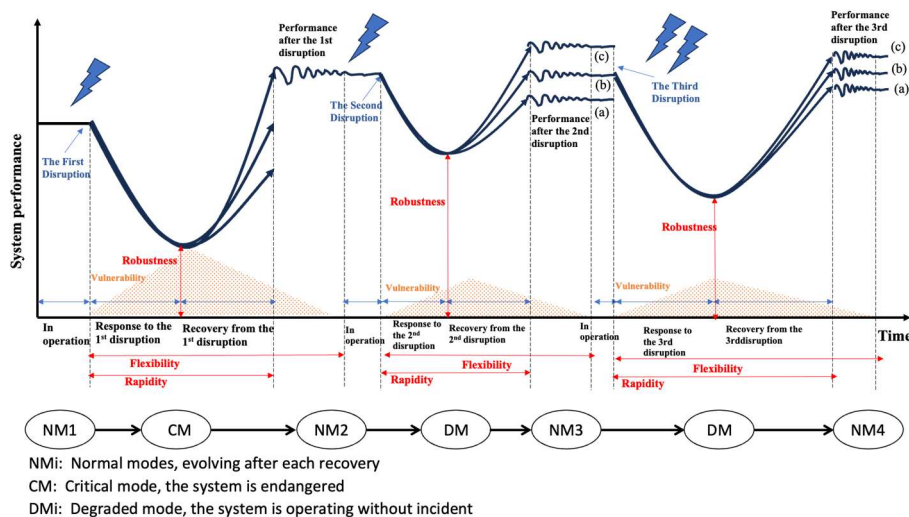


Fig. 5. Resilience and related concepts

With regards to all the concepts discussed above, resilience in production system can be redefined as the following:

*"Unlike robustness, which relies on rigid processes resistant to disruptions, resilience is the capability of a system to reach a stable state after a disruption by adopting updated or new processes. This enhances flexibility, shortening the time needed to achieve stable performance. The learning from this process reduces the system's vulnerability."*

## 6 Conclusion

The resilience of a system comes with different definitions in different domains in the literature. However, there is a common point among all the definitions, resilience is a response to unexpected or unforeseen changes and disruptions, and an ability to adapt and respond to such changes. Despite this



common understanding of the concept, resilience could be largely misplaced by the concept of “tolerance” or “the “ability to resist” in the system while facing disruption. On the other hand, it could be interchangeably used by concepts like “flexibility” or “robustness”. On the other hand, it is known that after the disruption and if the system was capable to bounce back, there might be some evolutions in the performance of the system, thanks to new or updated processes. the role of this revolution and the lessons learnt after several disruptions seem to be missing from the literature as well. To that point, the article conducted a study with two objectives:

- O<sub>1</sub>: Define the resilience graph, taking into account the system's experience after several disturbance.
- O<sub>2</sub>: Introduce a schematic presentation of resilience-related concepts such as flexibility, speed, scalability and robustness.

Regarding the first objective, resilience and the performance of the system were investigated while facing several disruptions with diverse magnitude. This study highlighted the effects of learning and experience in the systems performance after encountering the first disruption. Additionally, the impact of system evolution after each disturbance on the vulnerability of the system was discussed. It was shown that after each disruption, the impact and the probability of the disruption at the same magnitude will decrease, which makes the system less vulnerable with a higher resilience. On the other hand, if the system faces even a bigger shock, the probability of the failure for the system is reduced thanks to lessons learnt from the other disruptions and the enhanced resilience.

To address the second objective, this article studied separately the concepts of robustness and flexibility regarding the system performance after several disruptions. Moreover, the study tried to clarify the definition of resilience of the system while schematically positioning resilience with other related concepts like flexibility, rapidity, vulnerability and robustness. Consequently, a correlated redefinition of resilience is offered considering the studied concepts.

The findings of the present study are not experimental and will stay conceptual till the time they are verified and validated with case studies. As the future work, the viability of the propositions will be tested with the real industrial cases structured by the Horizon European project which has provided partial fundings to this study.

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