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A Framework For Structuring Resilience And Its Application To Procurement

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Abstract

Companies operate in an increasingly volatile environment where different developments like shorter product lifecycles, the demand for customized products and globalization increase the complexity and interconnectivity in supply chains. Current events like Brexit, the COVID-19 pandemic or the blockade of the Suez canal have caused major disruptions in supply chains. This demonstrates that many companies are insufficiently prepared for disruptions. As disruptions in supply chains are expected to occur even more frequently in the future, the need for sufficient preparation increases. Increasing resilience provides one way of dealing with disruptions. Resilience can be understood as the ability of a system to cope with disruptions and to ensure the competitiveness of a company. In particular, it enables the preparation for unexpected disruptions. The level of resilience is thereby significantly influenced by actions initiated prior to a disruption. Although companies recognize the need to increase their resilience, it is not systematically implemented. One major challenge is the multidimensionality and complexity of the resilience construct. To systematically design resilience an understanding of the components of resilience is required. However, a common understanding of constituent parts of resilience is currently lacking. This paper, therefore, proposes a general framework for structuring resilience by decomposing the multidimensional concept into its individual components. The framework contributes to an understanding of the interrelationships between the individual components and identifies resilience principles as target directions for the design of resilience. It thus sets the basis for a qualitative assessment of resilience and enables the analysis of resilience-building measures in terms of their impact on resilience. Moreover, an approach for applying the framework to different contexts is presented and then used to detail the framework for the context of procurement.

Keywords

Resilience; Framework; Disruptions; Resilience Principles; Procurement

1. Introduction

Companies and their supply chains have frequently experienced different kinds of disruptions. Especially the COVID-19 pandemic as a recent example of a global crisis has caused major challenges in supply chains. According to a study by GYA ET AL. 80 % of the companies surveyed were affected and the pandemic resulted for example in shortages of critical materials, delayed deliveries and longer lead times, and difficulties in planning and adjusting production capacity to meet fluctuating demand occurred [1]. Disruptions are especially critical when they affect the procurement side [2]. A study by BVL demonstrated that disruptions impacts on the supply side have been considered worse [3]. Despite the frequency of disruptions, several developments lead to increasing complexity in supply chains making it more difficult to create transparency [4]. In this volatile environment, companies are not sufficiently prepared for disruptions. One way of dealing with disruptions is increasing resilience. Resilience enables a system to cope with even unexpected disruptions and to ensure competitiveness. [5,6] Building resilience is largely dependent on measures taken before a disruption occurs [7]. However, currently many companies do not systematically increase their resilience even though the importance of resilience is widely acknowledged [8]. As resilience is a multidimensional and complex construct, implementing resilience requires an understanding of its constituent parts. However, a common understanding is currently lacking. [9,10] It is thus necessary to decompose the multidimensional concept into its individual parts and understand the relationships between them. This paper aims at structuring resilience by developing a framework that strengthens the understanding of resilience. It, therefore, supports the analysis and design of resilience. Additionally, the proposed framework is applied to the context of procurement. The framework serves as a basis for a qualitative resilience assessment which is a prerequisite for systematically designing resilience. The remainder of this paper is organized as follows: Section 2 reviews the literature regarding resilience and existing frameworks for analyzing it. Section 3 presents the developed framework and section 4 summarizes the application of the framework to the context of procurement. Section 5 gives an outlook on the use of the framework.

2. State of the art

In this section, the term resilience in the context of supply chains and procurement is defined first, before existing frameworks for analyzing resilience are summarized and the research need is presented.

2.1 Definition of resilience

As stated before, resilience is a multidimensional concept that is used in various contexts like ecology, psychology, supply chain and economy. Currently, there is no common definition of resilience in the fields of supply chains and organisational resilience. [6] ANNARELLI AND NONINO distinguish between static and dynamic organisational resilience. While static resilience focuses on preventive actions to decrease the impact of disruptions, dynamic resilience aims at reactions and fast recovery [11]. According to ALI ET AL. supply chain resilience definitions differ in terms of the phases considered, the strategies covered and the abilities addressed. Phases of resilience include the periods before, during and after a disruption. Strategies that are covered in the definitions are proactive, reactive and concurrent. To distinguish between the abilities that are considered within the definitions ALI ET AL. identify the abilities to anticipate, to adapt, to respond, to recover and to learn. Based on these constructs, supply chain resilience definitions can be divided into narrower definitions that include only individual aspects of the phases, strategies and abilities and wider definitions that imply all phases and strategies. [9] This work chooses a comprehensive view and understands **resilience** as the ability of a company to prepare for potential disruptions, react and adapt to disruptions as well as the ability to return to the original state or achieve a better state after the disruption. The aim is to minimize the impact of disruptions through preventive measures and return to the original state as quickly and cost-effectively as possible. A **disruption** in this context is a temporary impact on the performance caused by the occurrence of a disruption event [12].

2.2 Resilience frameworks

The frameworks reviewed in this section can be divided into different categories: frameworks related to the resilience triangle, the disruption profile or both and frameworks related to resilience capabilities. The **resilience triangle** by BRUNEAU ET AL. is a quantitative measurement tool for the seismic resilience of communities. For measuring resilience the authors examine the performance development over time after a disruption and identify the time needed for recovery, the severity of the disruption measured as the drop in performance and the area between the original and the actual performance as resilience dimensions. [13] MELNYK ET AL. analyze the transient response of a system and build on a profile similar to the resilience triangle. The authors identify the time between the occurrence of the disruptive event and the disruptive effect, the time at which recovery sets in, the comparison between the original performance level and the performance level after recovery, and the area between the original and the actual performance level as relevant resilience dimensions. [14] SHEFFI AND RICE propose a **disruption profile** that describes the development of the performance over time and identify eight phases that characterize this profile [15]. MUNOZ AND DUNBAR apply the resilience triangle and refer to the disruption profile to observe the response behavior of actors in a supply chain. In addition to the original dimensions of the resilience triangle, they identify the profile length and the weighted sum as two dimensions that explicitly take into account the curve progression. [16] BEVILACQUA ET AL. combine the resilience triangle and the disruption profile to categorize the eight phases of the disruption profile for the supply chain context [17]. Frameworks that refer to **capabilities** qualitatively analyze resilience. PETTIT ET AL. distinguish between vulnerabilities and capabilities when analyzing resilience. While vulnerabilities decrease resilience, capabilities enhance resilience. [18] ALI ET AL. develop a framework that contains five capabilities and 13 corresponding elements. Additionally, the elements are detailed in practices that support building resilience. [9] DUCHEK focuses on organizational resilience and proposes a framework containing anticipation, coping and adaption capabilities. [10] The framework developed by GIANCOTTI AND MAURO includes five resilience phases and corresponding capabilities [19].

2.3 Research needs and requirements for the resilience structuring framework

The various definitions and different frameworks underline that there is no common understanding of resilience. Starting from the definitions, different authors set various focal points and thus include different aspects in their definitions. Additionally, existing frameworks take different perspectives. In the cases where authors identify specific components of resilience in their frameworks, these components differ across the analyzed frameworks. The frameworks considered are not sufficiently detailed to analyze the contribution of concrete resilience increasing measures. Moreover, the frameworks are not applied to the context of procurement. Overall, the analysis of existing approaches illustrates the lack of understanding of the building blocks of resilience. Thus, the remainder of this paper focuses on developing a framework that captures the different aspects of resilience. The framework needs to identify specific components which constitute resilience and especially take into account the different phases of resilience. Additionally, the components need to be structured to incorporate their interrelationships. For each component, the target direction for increasing resilience must be identified. This is especially important as the framework sets the basis for analyzing resilience increasing measures regarding their contribution to resilience. The developed framework should be generic and applicable to different contexts for example to procurement.

3. Development of a framework for structuring resilience

The proposed framework builds on the existing frameworks and contains different components that characterize resilience. First, a structure for the framework is proposed based on existing definitions of resilience that contains three main component groups. Then, the individual components for each group are identified by analyzing the existing approaches. Lastly, resilience principles which are understood as target directions for the systematic design of resilience are derived based on the identified components.

3.1 Structure of the framework

The analysis of existing definitions and frameworks demonstrates the dynamic aspect of resilience. When analyzing resilience different phases are of importance. In general, resilience influences the time before, during and after a disruption. [9] The first category of components, therefore, are **time-related components**. Additionally, resilience is defined through an intensity aspect [20]. Resilience focuses on the impact of disruptions on performance. Thus, the second category comprises **performance-related components**. These dimensions are also the basis of the above-described framework groups “resilience triangle” and “disruption profile”. As the disruption profile characterizes the time-related aspects and considers the performance, it will serve as a basis for identifying and framing the resilience components. Following the resilience triangle, the area between the original performance and the actual performance after a disruption can be used to characterize the resilience of the system considered. The smaller the area, the more resilient the system is. This area is not only influenced by the time and performance amounts but also by the progression of performance over time which is represented by the curve trajectory. The third category thus describes **curve-related components**. The structure of the framework is presented in Figure 1.

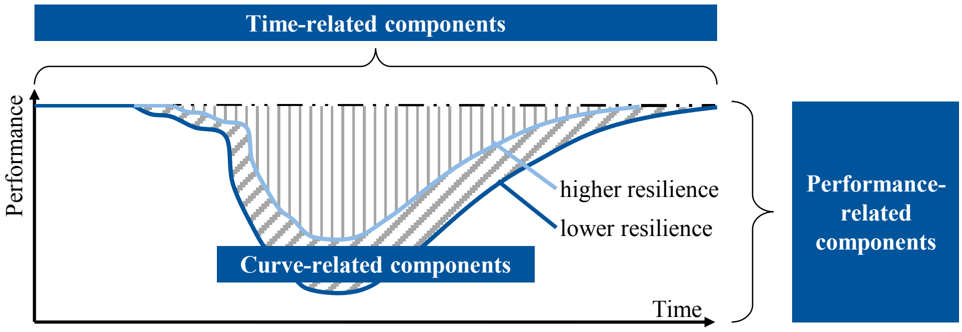


Figure 1: Framework structure

Time-related aspects specify the x-axis, whereby performance-related aspects define the y-axis and curve-related aspects characterize the curve progression. The analysis of the area in terms of opportunities for its reduction serves as a basis for identifying **resilience principles**. They indicate how the resilience components need to be modified to achieve higher resilience. Thereby, two overarching goals of resilience can be distinguished. On one hand, passive resilience aims at increasing the robustness of a system. A high robustness results in the least possible impact in the case of a disruption. On the other hand, active resilience aims at fast adaption and recovery when a disruption impact occurs. [21,22] The specific components and the corresponding resilience principles are described in the following.

3.2 Time-related components and resilience principles

For describing resilience the time before, during and after a disruption are important. Within this framework, time-related components refer to periods in the disruption profile which are defined by a start and endpoint. Before characterizing the time-related components it is, therefore, necessary to identify the relevant points in time. HEIL has characterized disruptions in terms of their time aspect and has identified several points in time that can be distinguished when analyzing a disruption [23]. A major point in time is the **occurrence of the disruption event (t_0)**. For the considered system the **start of the disruption impact (t_1)**, which can be observed through a decrease in performance, as well as the **end of the disruption (t_4)** are further relevant points. [23] Depending on the system state the occurrence of the disruption event and the start of the disruption can be separated points in time. The end of the disruption is characterized by reaching the original performance level in case of a full recovery or through reaching a new state of equilibrium in case of a partial recovery. For analyzing resilience components the point in time where it is known that the disruption event has occurred (**knowledge of the disruption event (t_2)**) is important as well. The last important point in time is the **lowest point of the performance curve (t_3)** as it marks the beginning of the recovery.

The first resilience component is defined as **buffer time**. A main aspect of resilience is concerned with minimizing the impact a disruption has on a system and ideally staying on the original performance level [21,16]. This component relates to the latent disruption phase as it is described by HEIL. It starts when the disruption event occurs and ends with the beginning of the disruption impact. [23] The existing system structure prevents a negative influence of the disruption. These structures are already present before the disruption occurs. Thus, the buffer time directly relates to robustness. The buffer time reflects the absorptive capacity of a system which ensures that the performance does not decrease even after a disruption event has happened. To increase the resilience this time should be as long as possible. The corresponding resilience principle is thus the **buffer time extension**.

Resilience is significantly characterized through the reaction in case of a disruption. In this context, the period that passes before recovery starts is an important feature of resilience. [6,14] The second component is thus called **response time**. In this framework, the response time includes the time that is needed to choose and implement specific actions. As a distinction to the buffer time, this component is linked to a concrete interference in the system. The response time begins with the knowledge of the disruption event. It ends when the measures take effect and the performance increases (the lowest point of the performance curve). The point in time when knowledge of the occurrence of the disruption event exists can be detailed when it is set in relation to other points in time. When looking at one system, the earliest point where the disruption can be known is the occurrence of the disruption event. However, it depends on the system characteristics if the disruption event is discovered right away. It is known at the latest when the disruption impact takes place. Depending on when the disruption event is discovered, the response time and the buffer time can overlap. The length of the response time is influenced by different latencies that can occur between an event and the effectiveness of countermeasure. These latencies contain the time that is needed to discover the event, analyze it, decide on the measures taken and the time for the measures to be effective [24]. Moreover, the response time depends on the available resources within the system. [6]

The response time corresponds to two resilience principles. First, the response time helps to increase the resilience when it is as short as possible. The shorter the response, the faster the lowest performance level is reached and recovery starts. Thus, the first resilience principle is **response time reduction**. Additionally, the start of the response time influences resilience. As the response time includes the time needed to choose measures and the time needed for these measures to become effective, an early start of the response results in earlier effective measures. The second resilience principle corresponding to the response time is therefore **response start shortening**.

The last time-related component refers to the recovery which occurs after measures take effect. This is also one of the two central aspects of the resilience triangle [13]. **Recovery time** is therefore proposed as the third component. The recovery time starts when the performance curve starts increasing. The end of the recovery time depends on whether a full or a partial recovery occurs. As described above, in the case of a full recovery the end is characterized by the fact that the original performance level is reached. For partial recovery, the end is determined by reaching a new equilibrium state of performance. The recovery time is characterized by an increase in performance caused by effective measures that have been taken. Like the response time, the recovery time leads to an increase in resilience when it is as low as possible. The corresponding resilience principle is thus called **recovery time reduction**.

3.3 Performance-related components and resilience principles

As described above, performance-related components refer to changes in performance that occur due to a disruption. They demonstrate the intensity of the disruption impact. Within the proposed framework, performance-related components are characterized through the difference between the original and the actual performance level during the disruption at a certain point in time. To identify relevant components, the extreme values in the curve are analyzed.

One important aspect is the maximum impact a disruption has on a system. This characterizes the severity of a disruption [13,16]. Following the resilience triangle and the disruption profile, the **maximum performance reduction** is defined as the first component. A high resilience is reached if the maximum performance reduction is as low as possible. This target dimension can be directly derived from the resilience triangle. Thus, this component relates to the resilience principle **damping of the maximum performance reduction**.

Additionally, the long-term performance level after the recovery has taken place is important [14]. As described above, either a full recovery or a partial recovery is possible. In the case of a partial recovery, the performance level after the recovery time has reached a new equilibrium state that is below the original level. Thus, the second component is defined as the **long-term performance reduction**. This aspect is also considered within the disruption profile [15]. This component characterizes the recovery capacity of a system. Similar to the above-described resilience principle, the target direction for the long-term performance reduction is its decrease. The optimum is reached if no long-term performance reduction exists. The corresponding resilience principle is therefore called the **damping of the long-term performance reduction**.

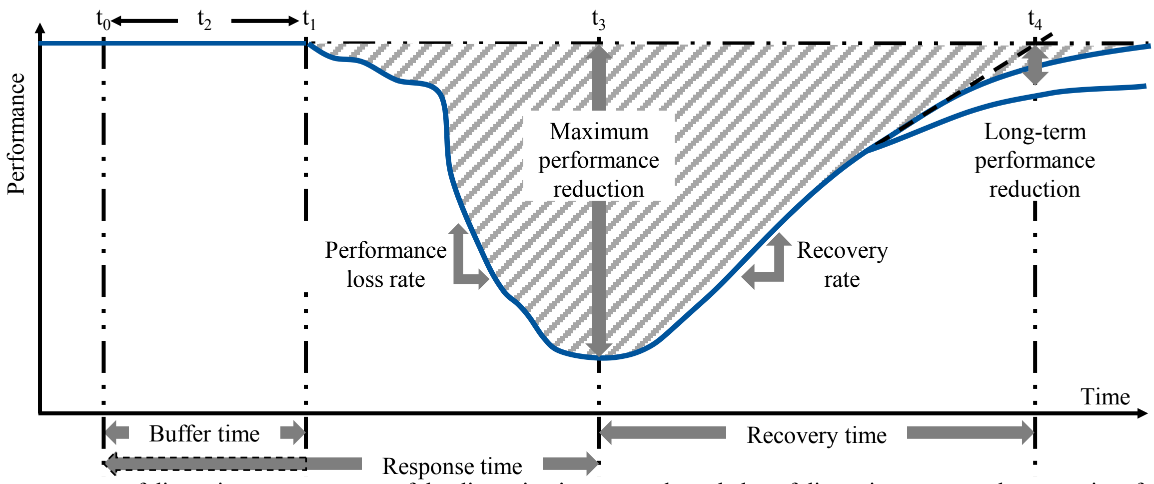
3.4 Curve-related components and resilience principles

The curve progression influences the area between the original and the actual performance level both during the reaction and the recovery time. To take into account different kinds of curve progressions, MUNOZ AND DUNBAR define the weighted sum and the length of the profile as two factors for measuring resilience. [16] Both factors are significantly influenced by the gradient of the curve. This corresponds with the approach of CIMELLARO ET AL. who describe different recovery functions like linear, exponential and trigonometric to distinguish between different kinds of recoveries [25]. For the curve-related components of the proposed framework, the focus thus lies on the gradient of the curve.

The first curve-related component is defined as the **performance loss rate**. It refers to the gradient of the curve during the response time when the performance decreases. A high performance loss rate results in a high performance decrease in a short amount of time. This component is both influenced by the characteristics of the disruption as well as by the response behavior of the system. A low performance loss rate results in a slow and possible controlled reduction of performance. High resilience is thus reached if the performance loss rate is as low as possible. This results in the resilience principle **performance loss rate reduction**.

Despite the time required for recovery and the performance level reached after the recovery, the recovery of a system is characterized through the rate at which recovery takes place. The second component is thus defined as the **recovery rate**. The recovery rate is influenced by the effectiveness of the measures taken. In contrast to the performance loss rate, the recovery rate should be high to ensure a high resilience. This component thus corresponds to the resilience principle **recovery rate increase**.

Figure 2 shows the developed framework with the identified resilience components.



t_0: occurrence of disruption event, **t_1**: start of the disruption impact, **t_2**: knowledge of disruption event, **t_3**: lowest point of the performance curve, **t_4**: end of the disruption

Figure 2: Resilience framework with components

Resilience can be characterized through seven components in the dimensions of time, impact and curve progression and the eight corresponding resilience principles. By using the disruption profile as the underlying structure, the framework takes into account the relationship between the identified factors. Additionally, the consideration of the area in combination with the described resilience principles details the multidimensional construct of resilience and points out various targets for systematically configuring resilience.

4. Application of the framework to procurement

The developed framework is generic and thus applicable for different contexts. In the following, an approach for applying the framework to different contexts is presented and illustrated for the area of procurement

The disruption profile is significantly influenced through the disruption, its impact and the different points in time. These aspects depend on the system under consideration. Therefore, the proposed framework applies to a specific object where a disruption impact can occur. For each object, a separate disruption profile has to be considered. However, often there are interactions between different objects. This is enhanced as disruptions are often complex and characterized by cause-effect chains that result in multiple level disruptions. Thus, a disruption impact happening at one object can cause a disruption impact at a linked object. In the framework, this is represented by looking at several disruption profiles that are linked by transition times. The link can concern both a physical material flow and an information flow. A link that concerns the material flow can lead to cascading disruption impacts if the system does not recover in time. A link that affects the information flow between two objects can influence the start of the response time. As described above, when looking at one object the response time starts between the occurrence of the disruption event and the start of the disruption impact. When taking into account several objects, the response time can already start when knowledge about a disruption occurs in a linked object if it is known that the disruption in the earlier stage will also affect the considered object at a later stage. For this to be effective, the information needs to be passed on between the objects.

To apply the framework to a specific context, a three-step approach is proposed: First, the relevant **performance values** must be characterized. The performance values specify the parameters whose changes in the disruption course are considered. Then, the **objects under consideration** need to be identified by analyzing the existing resources and possible disruption impacts. Lastly, when looking at several objects the **transition times** need to be specified.

For the context of procurement, the relevant **performance values** are identified in the following. The overall goal of resilience is to minimize the negative aspect a disruption has on the performance. Thus, the focus lies on the disruption impacts rather than on the disruption event or the disruption source. This is especially suitable as a large number of disruption sources leads to a limited number of impacts [26]. For the application of the framework to the context of procurement potential disruption impacts as well as overall goals of procurement are analyzed. Potential disruption impacts in procurement that are mentioned in the literature are a lack of material [26], business interruptions [27], deviations from the expected quality, planned quantity, planned delivery date or planned price [28], supply at the wrong time or supply of the wrong products [29] and differences between the desired and the actually supplied quantity [30]. Looking at these impacts it becomes apparent that when considering the physical material flow the impacts relate to missing material. Thus, *material availability* is chosen as the performance value. Material availability is the supply of the right material, at the right time, in the right quality, in the right quantity, at the right place [31]. This performance value corresponds with the overall goal of procurement. Namely, to ensure the long-term supply security of the enterprise for the production of goods [32].

The **objects** for which a disruption profile needs to be considered and their **interdependencies** are derived from the structure and resources in procurement. The procurement function links manufacturers and suppliers. Typical actors within a procurement chain include suppliers, manufacturers, logistical service providers and distributors [33]. The application of the framework in the context of procurement focuses on manufacturers. As the *goods receipt* is the direct interface to the suppliers or the logistical service providers, it serves as the central object that is considered. Material availability is influenced if the material is not supplied at the planned delivery date. The *production* is the internal demand source of the goods receipt. It is thus defined as the second object. A deviation in material availability occurs when input material for the production is not available at the planned date. To display the information linkage between the goods receipt and the external supply market, a third object is considered. This object comprises suppliers and logistical service providers as they both execute deliveries to the manufacturer. This object is called *external input actor*. Material availability at this object influences the ability to deliver. Goods receipt and external input actors are linked by procurement logistics while intralogistics links goods receipt and production. The transition times are the time needed for the transport respectively the time needed for the provision of material. The resulting resilience model is summarized in Figure 3.

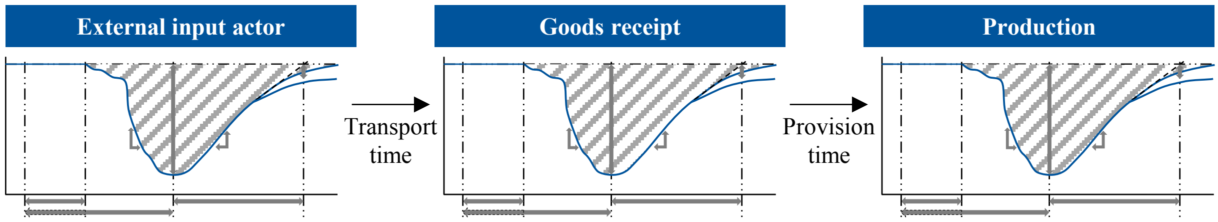


Figure 3: Resulting resilience model for the context of procurement

Each of these objects can experience deviations in material availability as a disruption impact. Additionally, an object can act as a disruption source for a subsequent object. For example, if a supplier is unable to deliver due to a production machine failure, the performance in the disruption profile of the external input actor decreases. Depending on the time needed for recovery, this can cause a performance decrease in the disruption profile of the goods receipt, if the material is not supplied at the planned delivery. Contingent on what resilience measures are in place at the goods receipt, a disruption impact can occur at the production.

5. Summary and outlook

Resilience is a multidimensional construct where understanding of its constituent parts is currently lacking. Such an understanding is the necessary foundation for analyzing and designing resilience. Therefore, a framework for structuring resilience has been developed. The framework builds on the disruption profile and the resilience triangle and contains seven resilience components. Additionally, it proposes eight resilience principles as target dimensions for building resilience. The generic framework can be applied to different contexts by defining the relevant performance values and the objects that need to be considered. This has been demonstrated for procurement. The framework thus sets the basis for systematically analyzing resilience improving measures regarding their specific contribution to resilience. Based on these results resilience can be configurated systematically. The paper contributes to an understanding of resilience, especially in the context of procurement. Further research is needed to identify concrete measures that increase resilience in procurement and analyze their contribution to the identified resilience principles.

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Biography

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