Sustainable performance management using resilience engineering

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Abstract
Several efforts have focused on the continuous improvement of firm performance, but many disturbances still occur because of various random failures. Resilience which is the ability to withstand shock and maintain critical function, has been recognized as an important approach to keep a firm operating in varying conditions, even if these conditions are excepted or not. With the objective to further enhance firm performance and be part of a sustainable development, it is necessary to study this performance through the resilience in order to manage all disturbances. The objective of this work is to propose a specific management model able to define the functions and barriers that contribute to the resilience of sustainable performance of firm. In this paper, the methodology is explained in detail, and its application trough textile firm is discussed.

Keywords
Firm performance, sustainable development, sustainable performance, resilience engineering, resilient performance

Introduction
Firms are currently evolving in a context which is under pressure on natural resources, competition in international markets and the challenges of attracting and retaining a qualified and healthy workforce. This pushes them to find themselves in the obligation to satisfy several imperatives related to sustainable development and to adopt a global vision to help managers to manage the proper functioning and overall performance of their systems. Improving this performance in order to generate more wealth is a constant concern of any manager. These systems must now be operated in an increasingly secure manner by adopting a global vision to develop the reactivity or flexibility of the system in the face of changes in its internal and external environment.

Overall performance is the desired objective of each company. However, the big challenge in overall performance lies in its own title. Its global connotation is synonymous with the integration of several aspects and not only the economic aspect but also the social and environmental one.

Economic performance consists in achieving the profitability desired by companies with the turnover and market share which preserved the sustainability of their activities.1,2

Environmental performance is always presented as a complex concept and source of several ambiguous interpretations.3 Generally, it is defined by the set of measurable results of the Environmental Management System (EMS) (ISO Standard 14031, 1999) or of environmental efficiency.4 The EMS makes it possible to define the objectives in terms of environmental performance.

Social performance reflects the way in which companies integrate ethics and responsibilities in their operations with the various stakeholders: customers, employees, suppliers,

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investors, civil society, environment. These responsibilities require that companies act responsibly toward stakeholders and motivate employees in order to create value.

The interactions between these three types of performance have given rise to the emergence of the global nature of performance. Indeed, several studies have highlighted mutual influences between these three performances: relationship between environmental and economic performance, relationship between social and economic performance, or the simultaneous interactions between these three types of performance which has been at origin of the actual appearance of global performance and sustainable development.

Therefore, overall performance and sustainable development are multidimensional. They result from the interaction between social, economic and environmental dimensions.

Slaper and Hall (2011) defined a sustainable business as one that “creates profit for its shareholders while protecting the environment and improving the lives of those with whom it interacts.” Integrating the principles of sustainable development into the company allows achieving effective results in terms of profitability.

The integration of sustainability in specific aspects of the company has been used in a wide variety of applications: supply chain management, operations management, product conception, ergonomics, integrated management systems, innovation, project management. In addition, there is always a challenge of integrating the principles of sustainable development for a global and sustainable performance of companies.

Sustainability is a collective term for everything related to the responsibility of all stakeholders in decision-making. In 2010, UN Global Compact indicated that sustainability has become an important issue for companies looking to create a competitive advantage in the global market. Companies are increasingly responsible for the sustainability of performance.

In this work, we present a new representation of resilient performance that guarantees the sustainability of company’s performance. According to Hollnagel (2006), the resilience of an organization designates the capacity of a system to anticipate a disturbance, to resist it by adapting, and to recover by returning as much as possible to the state before the disturbance. Skovholt et al. (2016) suggest that a resilient individual is someone who has the “ability to rebound from a negative force.” The term “resilient” therefore refers to the ability of a system to return to a normal operating state after it has suffered an accident.

Every company that aims to maintain the sustainability of its overall performance is called upon to appropriate this resilient vision, acting whenever necessary to avoid or respond to disruptive events that may occur due to various technical failures, human or environmental ones.

The main difficulty in studying the resilience of a company’s performance lies in its conceptuality. To theorize and manage this performance, it is necessary to identify the functions of a resilient performance and the barriers that make this performance sustainable. In this paper, these barriers are part of sustainable development. The objective is to propose a specific management model able to define the functions and barriers that contribute to the resilience of the overall performance of a company while reconciling the various financial, social and environmental challenges. The following questions will be addressed:

- How to promote a resilient performance of a company by adopting sustainable development practices?
- What are the functional behaviors that a company must adopt before, during and after a disruption?
- What are the barriers that restore resilient performance?

**Literature review dealing with sustainable performance management**

There are several tools that deal with managing company’s performance. Some deal with environmental performance (environmental accounting, ISO 14000 standards, EMAS standards), others with social performance (societal accounting, SA8000 standards, AA1000 standards, social report). Others provide the global vision of performance such as the Sustainable Balanced Scorecard, the Triple Bottom Line, Life Cycle Sustainability Assessment (LCSA) and GRI reporting. We only review the tools that present the global dimension of performance.

The Balanced Scorecard, also called a prospective dashboard, is based on the work of Kaplan and Norton (1993). In its initial version, it is a table that combines financial and operational measures classified according to four dimensions: financial results, customer satisfaction, internal processes and organizational learning. It is one of the best measurement tools to achieve objectives and performance results. However, this version is oriented to economic and financial results and cannot be considered as a tool for assessing overall performance. Indeed, in its initial version, BSC does not take into account environmental and social aspects. As a result, the BSC has been combined with the parameters of sustainable development and takes a new name: Sustainable Balanced Scorecard (SBSC). It is a promising framework for measuring and reporting the results of the company’s sustainable strategy or even to use as a planning tool.

The Triple Bottom Line (TBL), a concept developed by Elkington (1998), is one of the recent contributions that focuses on the three axes of sustainable development. It states that for a company to be sustainable, it must be financially strong, it must minimize or eliminate its negative environmental impacts, and ultimately, it must act in accordance with social expectations. It is an approach that unites the concept of sustainability with performance. This notion is a framework for measuring and
reporting the results of an organization according to economic, social and environment parameters. 

Life Cycle Sustainability Assessment (LCSA) is an approach that combines three life cycle tools: Environmental Life Cycle Assessment, Life Cycle Costing, and Social Life Cycle Assessment. It consists in studying the environmental, social and economic impacts of a product. Some authors have developed work on LCSA by explaining that the assessment of a sustainable life cycle should include social, environmental and economic aspects. The approach for the simultaneous implementation of these three aspects in the complete life cycle of a product is still poorly defined. Advanced work in this direction is limited to only one or two aspects.

The GRI Reporting defines guidelines for the implementation of sustainable development reports. It is the most advanced and recognized standard that provides an approach that encompasses the different dimensions of sustainable development at the company level. GRI reports are also an assessment tool for measuring and reporting on the environmental, social and economic performance of companies. In addition, it offers performance indicators distributed over the three dimensions of sustainable development.

All of these tools have been used to assess and measure the sustainable development aspects of companies. Several research works have developed methods dedicated to this objective. Among the most frequently used methods: the analytical hierarchy process (AHP), Multi-Criteria Decision-Making Method (MCDM), Fuzzy Theory, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Holistic Approach, Value Stream Mapping (VSM), and Fuzzy Theory. Note here that most of the VSM-based tools present only the environmental aspect of corporate sustainability.

Other authors have developed approaches that combine several of these methods. For example, Pask et al. (2017) present a theory of fuzzy sets combined with Monte Carlo simulations to assess the sustainability of industrial ovens. Hsu et al. (2017) define an approach that combines the deployment of the quality function and the fuzzy Delphi method to measure the correlations between performance indicators and sustainable development criteria. In Chen et al. (2015), the authors present a combination of fuzzy set theory, Delphi method and discrete multicriteria method to improve sustainability indicators and reduce the overall impact on the environment in the construction industry in China. In Kumar and Anbanandam (2020), the authors propose a framework that integrates multi-criteria decision-making method and fuzzy logic to evaluate sustainability performance with an index and highlights the obstacles to the sustainable freight transportation system.

Amrina et al. (2016) propose a fuzzy multi-criteria approach to assess sustainable manufacturing in the cement industry by integrating the interpretative structural modeling methodology (ISM) and the FANP methodology (Fuzzy Analytic Network Process). FANP approach is also used in Wichert et al. (2019) in order to aggregate sustainability performance assessment of an industrial corporation.

In all of these works, sustainability of performance has been presented as being the use of a minimum of resources which do not pollute, do not have a negative impact on society and with an optimized cost, but they do not integrate the resilient potential of performance in the face of disruptive events. Resilience helps maintain sustainability and continuity of companies activities.

Resilience concept

Several definitions of resilience come from the concept of resilience engineering and depending on the research field, discipline, or also industry sector. Hollnagel (2006) defines resilience as the ability of a system or organization to react and recover from disturbances at an early stage, with minimal effects on dynamic stability. Leveson et al. (2006) present resilience as the capacity of systems to prevent or adapt to changing conditions in order to maintain (or control) the property of the system. In Becker et al. (2014), the authors present the concept of resilience with a societal dimension “emergent property determined by society’s ability to anticipate, recognize, adapt and learn from variations, changes, disturbances, disruptions and disasters that may cause harm to what human beings value.”

In Wang et al. (2019), the authors presented resilience in light of its implication to robots. In this case, resilient robot is a “robot that can recover its function after the robot is partially damaged.” In Zhang and Lin (2014), the authors gave more general definition of resilience applied to engineering. In that definition, the emphasis is on that there is a partial damage to a system in the area of structure that is needed to run the system or the condition upon which the system functions, which causes the system be sort of function or dysfunction, and the system recovers in a required time via the change of its structure and/or resource. In addition, the authors introduced to difference between resilience and robustness. The discussion of these concepts are more presented in several works. In general, robustness is presented as the capability of the system to perform its function under unpredictable disturbance. It’s an insensitiveness to a disturbance environment. In the light of these works, it’s very difficult to make a difference between resilience and robustness. Resilience principle can be presented from the following points: anticipation of a disturbance, resistance by adapting and recovery by regaining the state of before the disturbance. In this common definition of resilience, robustness can correspond to “resistance by adapting.” Therefore, we can say that robustness is included in resilience.

In the production firms, the concept of resilience has been used to describe the need to respond to disruptions.
in the business market. In Saloua Said et al. (2019), the authors presented resilience as processes and highlighted their role to maintain the functioning of the other processes in the system. It allows a firm to survive or to transform challenges into opportunities. In this perspective, performance improvement approaches can no longer be satisfied with preventing the occurrence of disturbances and understanding their causes. They also should aim to enable systems to act flexibly in constantly changing and uncertain environments.

According to these definitions, firm is seen according to a systemic approach, for which a representation and a characterization of disturbances and dysfunctions are necessary, and in front of these dysfunctions, the system adapts adequate behaviors and presents abilities to be more resilient.

Following the above, the concept of resilience engineering is an effective approach to managing organizational change that ensures company continuity in a changing and uncertain environment and which includes learning, adapting to changes, improving and anticipating disturbances. This justifies and strengthens the choice of this approach in this work.

In production firms, the application of the concept of resilience has relatively linked to the supply chain, occupational safety or manufacturing systems.

However, work closely linked to the resilience of a company’s performance as a whole and in the context of sustainable development has not yet been developed.

Research methodology

Research objectives

The main objective of this research work is to develop a resilience engineering model integrating sustainable development for sustainable company’s performance management. Our defended reflection is that the sustainable performance of a company does not only linked to the ability to articulate the management of continuous improvement with the management of available resources, but also linked to four “performance functions” which can characterize three main phases of a socio-technical system:

- phase before a disturbance or dysfunction: in this phase, the expected performance function of the system is the ability to anticipate. This function formalizes behaviors relating to the ability to identify the potentials of emerging disturbance scenarios;
- phase during a disturbance: the expected performance function is the ability to respond which formalizes the behavior of the system at the time of the accident;
- phase after a dysfunction: in this phase, two performance functions are expected: the ability to learn and the ability to survive.

For each function, performance barriers must be implemented which allows meeting the required skill. Hollnagel (2004) defines a barrier as “… something that can either prevent an event from taking place or protect against its consequences.”

In this paper, three types of barrier are distinguished to integrate the vision of sustainable development into the resilience of the performance: Barrier of Social Performance (BP.S), Barrier of Environmental performance (BP.En), Barrier de Economic Performance (BP.Ec).

Resilience engineering model for sustainable performance

According to the definitions of resilience presented in the previous section, we can resume them as follows: “resilience is the ability of a system to maintain or restore acceptable functioning despite disturbances or failures.”

The key concept of this definition and on which we have referred to develop our model is: ability […] to maintain or restore: we find this same concept in the definition of maintenance, in which the term “maintain” contains the notion of surveillance and prevention. The term “restore” contains the notion of correction after loss of function.

From this analogy, we consider a firm as a system with three states: normal operating state (NM), degraded state (DM) and critical state (CM). We present this system by the following state graph (Figure 1):

This model highlights the following states:

- Normal Mode (NM): the company operates without the occurrence of events that can disrupt its performance.
- Degraded Mode (DM): the company operates under latent conditions (conditions which present disruptive events which can impact its performance in the short or long term).
- Critical Mode (CM): the company is facing serious disruptions that threaten its performance.

The arches (a); (b); (c) model the transition from one state to another. We consider that the transition from NM to DM and from DM to CM will have various disruptions in the performance of a company.

To make the performance of a company resilient and sustainable, we must add other transitions. In each state, the company must develop a performance management function:

- In the NM state, the expected performance management function is ability to anticipate, to avoid ending up in the DM and CM state and to maintain the NM state.
- In the DM state, the expected performance management function is the ability to respond to regain the
NM state and the ability to anticipate in order to avoid ending up in the CM state.

- In the CM state, the expected performance management function is the ability to learn and survive in order to avoid remaining in this critical mode.

Proposal model for managing sustainable performance is presented in Figure 2.

Arcs (a') (b') (c') and (n) formalize the barriers that allow the transition of performance from one state to another. These barriers are social (BP.S), economic (BP.Ec) and environmental (BP.En).

Studying the behavior of these transitions indicates that performance resilience barriers are necessary to promote the performance functions described above, to prevent unwanted transitions and to accelerate the desired transition to a normal mode. Figure 2 shows the effect of these barriers on the transition of performance states. If the barriers are maintained and controlled, the performance state remains in the normal mode (transition n). If the barriers
between the degraded and critical modes are effective, the company can regain a normal operating state (the transitions a', b' and c').

The concept of modeling used here refers to the fact that these barriers can not only anticipate disruptions, but also help the performance of a company to rebound from a normal operating mode (which is specific to resilience measures). This model also reveals another new concept: a family of many barriers that are part of the sustainable development approach.

These barriers work and unite to improve the capacity of a company to maintain its performance in a sustainable state by tolerating the conditions of degradation and to rebound from disturbances instead of being deteriorated. It is assumed here that the complexity of managing sustainable performance is derived from the transition from one operating mode to another which depends on several social, economic and environmental barriers.

**Case study and application**

**Case study: Textile firm**

In recent years, textile companies have been rapidly increasing their market in the world. They are exposed to a highly competitive global market. It is a sector with a complex production system. This complexity lies in the presence of several processes such as the production of fabrics for clothing, industrial goods and even furniture. This diversity of textile products requires the use of high quantities of chemicals, raw materials, water and energy.

Several products used in the textile industry can cause not only environmental problems, but also health problems. Dyes are the most important pollutants.123–125

The dangers associated with the textile industry are mainly related to water pollution caused by the discharge of untreated effluents, as well as those due to the use of toxic substances.126 Other questions have arisen with the use of machines which have a high noise pollution due to moving parts and also give dust presenting a real danger for workers.

Textile industry presents a several environmental risks (rejection of waste, pollution), economic risks (high consumption of water and energy) and social risks (risks affecting the health and safety of workers).

**Application and discussion**

In this section, we demonstrate the application of the proposed methodology for managing sustainable performance in the textile industry through resilience engineering. The company studied in this work carries out a set of activities in the textile and clothing sector such as spinning, weaving, knitting and making. These activities contribute to the pollution of water by discharging a number of pollutants, originating both from the various impurities and residues already present in the raw materials, and from the substances added during the fabric manufacturing and treatment processes. They also contribute to air pollution and emissions related to the combustion of fuels. They are characterized by a high consumption of water, electrical and thermal energy used in the production of steam and the drying of the material. These activities also present several problems of noise and the use of chemicals harmful to health.

This company is still operating in a degraded mode due to the presence of a set of previously mentioned problems. To analyze the functions and barriers of performance management in this company that contribute to resilience, the transition from one mode to another is analyzed. Depending on a specific scenario, certain barriers can be applied to obtain a resilient and sustainable performance for this disturbance scenario. These suggested functions and barriers are presented in Table 1.

The analysis of this case study shows that the barriers that favor the functions of managing resilient performance are environmental, social and economic. Applying these barriers for each disruption scenario provides environmental and economic benefits and improves workplace conditions by protecting the health and safety of workers. For example, installing an energy recovery system will make it possible to achieve significant energy savings (economic impact) and a reduction in fuel consumption (environmental impact) which can generate savings of several million dollars per year (economic impact). The use of dust collector covers allows ensuring the protection of workers (social impact), and guarantying the production of a clean product (environmental and economic impact). The automatic dosing and feeding system for chemicals has great advantages over the manual method because it minimizes the risk of injury to workers when handling dangerous chemicals (social impact) and reduces lead times delivery (economic impact). The establishment of a system for monitoring substances at entry and exit to identify products makes it possible to avoid pollution (environmental and social impact). Use of machines with special covers to reduce noise and vibrations protect workers as well as the inhabitants of the neighborhood (social impact). Control of flow rates, automatic control of the filling volume and reuse of cooling water as process water are barriers that allow better management of water consumption (economic impact). The recovery of heat in the combustion gases or the separation of hot and cold water flows allows reducing the consumption of natural gas and therefore greenhouse gas emissions (environmental impact) and achieving very significant savings (economic impact). Textile waste recycling allows a circular economy by reducing the consumption of materials and resources (economic and environmental impact). The reduction in packaging promotes both the reduction in the cost of purchasing packaging material (economic impact) and the reduction in the quantity of packaging released into the environment (environmental impact).
Table 1. Performance management functions and sustainable barriers reflecting the resilience of the case studied.

| Disturbances                                                                 | Mode | Function Performance       | Performance barriers                                                                 | Barrier role                                                                 |
|------------------------------------------------------------------------------|------|---------------------------|--------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| The high mechanical stresses to which the fibers are subjected during spinning are accompanied by large amounts of dust. | DM   | Ability to respond         | - Use of special enclosures, dust collectors, and air conditioning systems           | -BP.En: Environmental Protection and BP.S: Protection of workers' health and safety |
| The strong mechanical stresses on the machines are accompanied by significant noise pollution and vibrations. | DM   | Ability to anticipate      | - Use of special enclosures, dust collectors, and air conditioning systems           | -BP.S: Protection of workers' health and safety                               |
| High water consumption                                                      | DM   | Ability to respond         | - Use flow control devices and automatic valves.                                   | -BP.Ec: Water Management                                                     |
| High energy consumption                                                      | DM   | Ability to respond         | - Recover heat from the combustion gases                                            | -BP.Ec: Energy management                                                   |
| Use of harmful chemicals                                                     | DM   | Ability to respond and Ability to anticipate | - Store any chemical according to the manufacturer's instructions                  | -BP.En: Environmental Protection and BP.S: Protection of workers' health and safety |
| Accidental chemical spills                                                   | CM   | Ability to respond         | - Provide sufficient back-up systems                                               | -BP.S: Protection of workers' health and safety                               |
| Leaks during the transfer of chemicals from storage to machines              | DM   | Ability to respond         | - Regularly check the pumps and pipes used for the transfer                         | -BP.En: Environmental Protection                                             |
| Liquid and solid waste streams                                               | DM   | Ability to anticipate      | - Appropriate training of workers                                                  | -BP.Ec: Reduction of resource consumption                                     |
The application of these barriers makes it possible to reinforce the resilience of this company while being part of a sustainable development approach. Each barrier promotes a performance management function, either by anticipating the appearance of a catastrophic event, by responding to working conditions presenting disturbances or by learning from incidents or accidents produced (by feedback). Depending on a specific scenario, certain barriers can be applied to obtain resilience for this incident scenario. This resilience is illustrated through these performance management functions.

**Conclusion**

This paper presents a resilience engineering model integrating sustainable development for companies performance management. The objective is to show how a resilience engineering model integrating the principles of sustainable development can manage disruptive events which allows maintaining a resilient and sustainable performance. It is a new representation of a company’s performance management through the development of a resilience engineering model distinguishing three interconnected modes of resilience. Each resilience mode has a performance management function which, in order to be successful, requires the establishment of barriers called performance barriers that integrate the three components of sustainable development. Analysis of the state transitions of the system revealed that resilience is translated into performance management functions provided by these barriers. These barriers interact together allowing a company to improve its operating condition. The proposed performance management functions are: ability to anticipate, ability to respond, ability to learn and survive. These functions serve as guidelines to help define the barriers allowing to ensure a given function which translates the resilience of the system by promoting at the same time economic performance, environmental performance and social performance.

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