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The concept of vulnerability and resilience

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Abstract

Vulnerability has been defined as the degree to which a system, or part of it, may react adversely during the occurrence of a hazardous event. This concept of vulnerability implies a measure of risk associated with the physical, social and economic aspects and implications resulting from the system's ability to cope with the resulting event. Concepts of resilience take two broad forms, namely (1) Hard resilience : the direct strength of structures or institutions when placed under pressure. In the disaster context, resilience is often treated as the simple inverse of fragility. Engineers, for example, often refer to increasing the resilience of a structure through specific strengthening measures to reduce their probability of collapse with respect, for example, to earthquake intensities, wind loading or other physical stresses. As resilience increases, the degree of damage for a given intensity hazard decreases. (2) Soft resilience : the ability of systems to absorb and recover from the impact of disruptive events without fundamental changes in function or structure. While the old car or carriage built on rigid supports would certainly end up with some broken axles when driving along some bad roads, the modern car can easily absorb the same impacts with its suspension system (springs or hydraulic systems). Thus, people with direct access to capital, tools and equipment, and able-bodied members are the ones which are most resilient when a disaster strikes. This paper shows how soft or hard resilience may be introduced in a system after it is analysed to determine its vulnerability.

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Keywords: Vulnerability; hazard; risk; resilience; disaster

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1. Vulnerability

1.1 Disaster

The word *disaster* is used in diverse ways, mostly to refer to any sudden, unexpected or extraordinary misfortune, regardless of number of people, size of region, or country or the entire world.

Any disaster, despite the diverse origins, has a number of common features:

1.A clear origin of the damaging process with characteristic threats.

2.The warning time is normally short, rarely accurately predictable, although they occur within a known hazard zone.

3.Most of the direct losses occur during or shortly after the event.

4.The exposure to hazard, or assumed risk, is largely involuntary, mainly because of the location of people in hazardous areas.

5.The resulting disaster occurs with an intensity that justifies an emergency response, varying from local to international scale.

1.2 Hazard and Risk

A naturally occurring or human-induced process or event with the potential to create loss is a *hazard*, i.e. a general source of danger. The actual exposure of something of human value to a hazard is a *risk* and it is often considered as the combination of probability and loss. Thus, a hazard is a potential threat to humans and their welfare, and risk (or consequence) is the probability of occurrence of a specific hazard (Sahni et al. 2001).

Imagine two boats, with one carrying a life jacket whereas the other is not. In case the boat overturns, the main hazard (deep water) is the same in both cases but the risk (probability of drowning) is greater for a person who does not know swimming and whose boat does not carry a life jacket.

Similarly, a landslide hazard can exist in both an unpopulated area and an inhabited one, but a landslide risk exists only for the inhabited area.

People and what they value are essential points of reference for all types of risk assessment of disasters. When a large number of persons exposed to a hazard are killed, injured, the event is termed *disaster.* Thus, a disaster is a realization of hazard, although there is no universally agreed definition regarding the scale on which loss has to occur in order to qualify as a disaster.

Hazard, risk and disaster operate on varying scales. Table 1 gives a list of threats in order of decreasing severity.

Table 1: List of threats

Hazards	Threats
People	death, injury, diseases, stress and trauma
Goods	property damage both to individual and State
Environment	loss of flora and fauna
Development	break in the pace of development, loss of livelihood

1.3 Vulnerability

The concept of *vulnerability* implies some risk combined with the level of social and economic liability, and the ability to cope with the resulting event. Vulnerability has been defined as the degree to which a system, or part of a system, may react adversely during the occurrence of a hazardous event.

Thus people become “vulnerable” if access to resources either at a household, or at an individual level is the most critical factor in achieving a secure livelihood or recovering effectively from a disaster. The households with

direct access to capital, tools and equipment, and able-bodied members are the ones which can recover most quickly when a disaster strikes. As such the most vulnerable people are the poorest, who have little choice but to locate themselves in unsafe settings.

Table 2 explains the various levels of exposure of persons and property to the different hazards that have been identified.

Table 2: Various levels of exposure to different hazards

Hazard	Exposure
Physical	Physical vulnerability relates to buildings, infrastructure and agriculture. Although the focus is on physical assets, it also includes the potential loss of crops and other infrastructure necessary to livelihood.
	Vulnerability analysis should examine the risk faced by critical facilities, which are vital to the functioning of societies in disaster situations, such as hospitals and dispensaries, emergency services, transport, communication systems, essential services, etc.
Social	Vulnerable groups include women, mentally and physically handicapped persons, children, and elderly persons, the poor people, refugees, and livestock.
Economic	Economic vulnerability assesses the risk of hazard-causing losses to economic assets and processes. These fall into two groups:
	Direct. Damage to or destruction of physical and social infrastructure and its repair or replacement cost, as well as crop damage
	Indirect. Loss to production, employment, vital services, income disparities

2. Resilience

2.1 Resilience of systems

Imagine a car going along a bumpy road. The passengers will feel the shocks, each time the car goes over a hump or on a pothole. However, if the car damping (shock absorbing) system is very good (or should we say efficient), the shocks will be barely noticeable, or even enjoyable for children as they slowly come back to their original position. Here, the car springs have the ability to absorb and recover from the impact of the shock of an uneven road surface.

This behaviour is in contrast to a boxer's practice sand bag, which barely moves under the boxer's fists hammering it, just as a brick wall will not move at all.

In each of the above examples, the system (car, sand bag, brick wall) has some characteristics which enable it to return (or to recover) to the original state. This is what is denoted by the resilience of a system. This is illustrated in Figure 1, which shows how a shock may affect a system's performance.

Thus, the concepts of resilience (Moench 2009) take two broad forms:

(a) hard resilience : the direct strength of structures or institutions when placed under pressure, such as increasing the resilience of a structure through specific strengthening measures to reduce their probability of collapse.

(b) soft resilience: the ability of systems to absorb and recover from the impact of disruptive events without fundamental changes in function or structure, which depend on the flexibility and adaptive capacity of the system as a whole, rather than simply strengthening structures or institutions in relation to specific stresses, as in the hard resilience approach.

2.2 Sectors needing resilience

A quick overview of resilience (Vale and Campanella 2005) may be obtained by examining a few cases of how

existing infrastructure (roads, drains, buildings, hospitals, industry) behaves under disturbances, such as floods, hurricanes, earthquakes, economic crisis). Table 1 provides a list of infrastructure systems which affect everyday life. However, once the concept of resilience is understood, it can be observed that the concept may be extended to a variety of sectors, as shown in Figure 2.

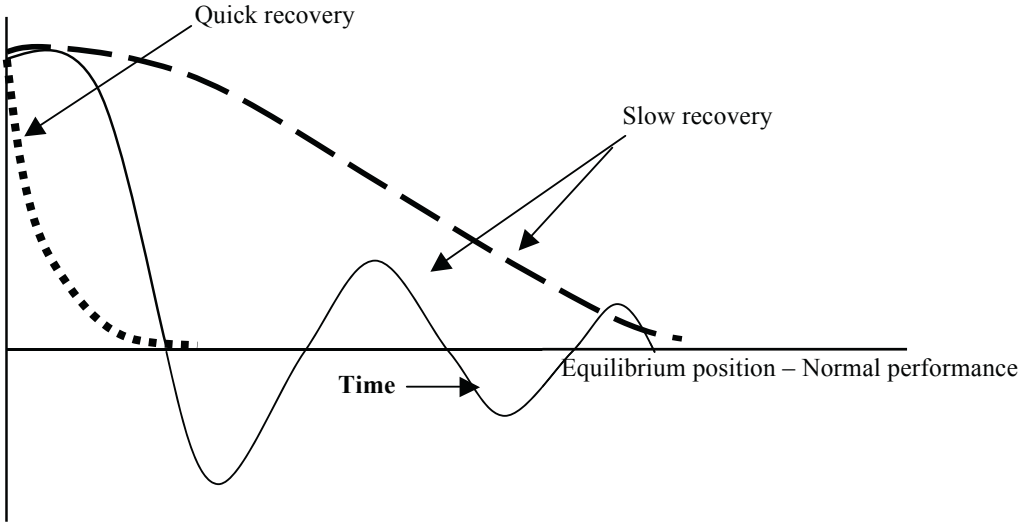


Figure 1. How a system returns to normal performance - equilibrium position

If the system behaves (Schipper and Burton 2009) in one of the ways illustrated in Figure 1, it is very likely that the system has been purposely designed to do so, and not just by chance. Generally speaking, whenever a possible disturbance is forecasted, there are three response possibilities (Handmer et Dovers 2009) to such threats:

1: Resistance and maintenance
This is characterized by resistance to change. A human system of this type would do its utmost to avoid change and would typically deny that a problem exists.
2: Change at the margins
This is characterized by acknowledgement of the problem, discussion of the implications, and, hopefully, a clear acknowledgement that the present system is not sustainable and that change is needed.
3: Openness and adaptability.
This approach reduces vulnerability by having a high degree of flexibility. Its key characteristic is a preparedness to adopt new basic operating assumptions and institutional structures.

Some of the reasons (Bruneau et al. 2003) behind such response lies partly in who makes cost/benefit decisions in a changing, competitive environment and who (taxpayers, private individuals, private enterprise) bears the cost of providing resilience. For example, faced with events that could destruct structures and harm employees, the benefits and costs of resilience must be evaluated from a holistic perspective so as to advise those concerned to make sound investment strategies. In particular, very few of the infrastructure of Table 3 can be said to be independent of the others, or in other words, would not affect others if it were itself disrupted during a disaster (Vugrin et al. 2010).

It is, therefore, judicious to look critically at Infrastructure Resilience as an integrated goal of identifying the time required to restore full functionality.

2.3 Definition of resilience

A suitable definition of system resilience is as follows:

A system is usually designed to behave in a certain way under normal circumstances. When disturbed from equilibrium by a disruptive event, the performance of the system will deviate from its design level. The resilience of the system is its ability to reduce both the magnitude and duration of the deviation as efficiently as possible to its

usual targeted system performance levels.

Figure 1, showing slow and quick recoveries, fully illustrates this definition.

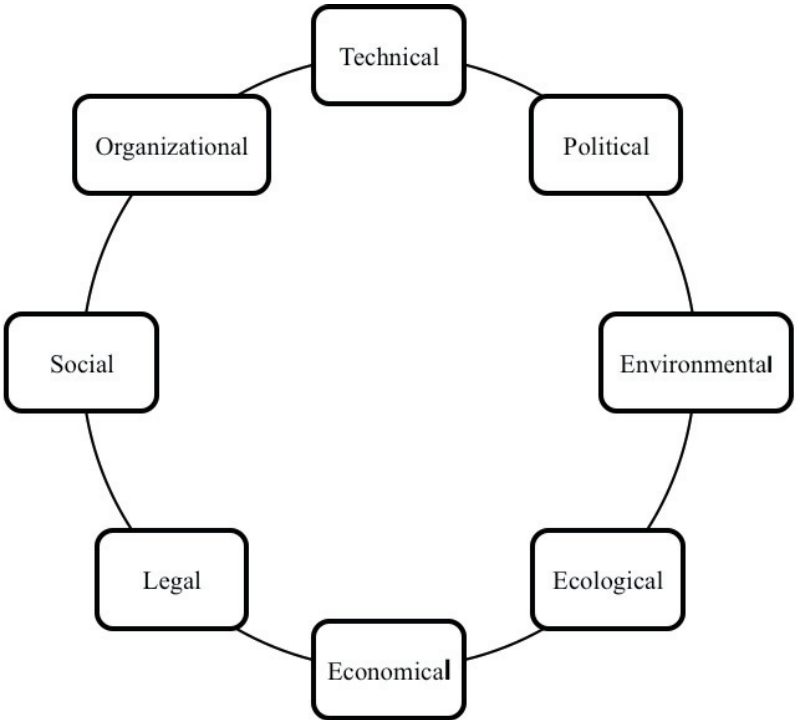


Figure 2. Sectors where system resilience may be important

Table 3: List of Infrastructure Assets

Sr. No	Infrastructure Asset	Sr. No.	Infrastructure Asset
1	Agriculture and Food	12	Government Facilities
2	Airport	13	Industrial Base
3	Banking	14	Information Technology
4	Chemical	15	Materials, and Waste
5	Commercial Facilities	16	National Monuments and Icons
6	Communications	17	Nuclear Reactors
7	Critical Manufacturing	18	Postal and Shipping
8	Dams, Emergency Services	19	Public Health and Healthcare
9	Defence	20	Seaport/Harbour
10	Drinking Water and Water Treatment	21	Transportation Systems
11	Energy		

System resilience will depend, at least, partly on inherent properties of – or those inbuilt in - the system. In

particular, three such properties or capacities (Fiksel 2003; Rose 2005)are used to define, quantify, and design for better resilience:

(1) *absorptive capacity*, or the ability of the system to absorb the disruptive event;

(2) *adaptive capacity*, or the ability to adapt to the event; and

(3) *restorative capacity*, or the ability of the system to recover.

Table 4 summarizes (Vugrin et al. 2010) the distinguishing characteristics of the capacities.

Table 4: Resilience capacities of a system

Component	System Impact		Total Recovery Effort
System Capacities	Absorptive. Endogenous feature	Adaptive Dynamic ability to change endogenously	Restorative Dynamic activities by entities exogenous to the system.
Capacity's Normal Features	Acts immediately after shock absorbing the impacts of system disturbance with little effort.	Actions taken over time after the shock, to move towards recovery	Ability of system to be repaired easily.
Examples	Storage can act as a buffer for flood water	Standby generators in case to cater for power breakdowns	Government repairs/renovates infrastructure. Repair crews.
Effort Required	Automatic/Little Effort	Internal Effort Required	External Effort often Required
Enhancement Features	System robustness – bigger drain, stronger beam System redundancy - alternate pathways, parallel circuits	Possibility of substituting components. Often rely upon the ingenuity of people faced with adversity. Food substitutes	System monitoring which can locate faults, enabling timely action (grid systems, telephone lines).
Measurement of Component	Internal measurement Important in the initial stages of disruptions.	Internal measurement Important in the initial stages of disruptions.	Exogenous measurement Repair of the system might be impossible in the short term.

2.4 Relationships between system capacities, performance, and recovery

Table 5 illustrates the system dependencies across systems (Vugrin et al. 2010) which can affect resilience capacities.

Table 5. Relationships between system capacities, performance, and recovery

Capacity	Relationships
Absorptive	If system A (buses, lorries) is dependent upon system B (roads) to operate, then this relationship will lower system A's absorptive capacity in scenarios that negatively affect system B (accidents, closed roads).
Adaptive	System A (heating) may have adaptive capacities that allow the system to reorganize (using wood, gas or other fuel) to reduce its dependency upon system B (oil)
Restorative	The operation of system A (gravity pipeline) may not depend upon the functionality of system B (electricity supply), but the repairs to system A may require system B to be operational. Difficult coordination may further reduce institutional restorative capacity

2.5 Resilience enhancement features and resilience sectors

Resilience enhancement features are often closely linked to the specific sector under consideration. Focusing on the long-term sustainability of companies, ecosystems, and social systems, Fiksel (2003) identifies four categories of characteristics of resilient systems that can also be considered as resilient enhancement features, such as:

(1) diversity, or "existence of multiple forms and behaviors";
(2) efficiency, or "performance with modest resource consumption";
(3) adaptability, or the "flexibility to change in response to new pressures"; and
(4) cohesion, or the "existence of unifying forces or linkages."

Table 6 summarises (Fiksel 2003; Rose 2007) the different enhancement features which can occur in different sectors.

Table 6. Enhancement features in different sectors

Sector	Enhancement features
Technical	Engineering based solutions that attempt to improve the functional performance level of the infrastructure system. A simple design may be more robust (hence, higher absorptive capacity), be easier to adapt (higher adaptive capacity), and easier to repair (higher restorative capacity).
Organisational	These organizations and institutions must attempt to choose an optimal recovery effort, taking into account the absorptive, adaptive, and restorative capacities of the system. The costs of recovery need to be compared against the speed of recovery.
Economic	The market price system, will automatically reduce the demand of a scarce resource after a disaster. Banning such price increases are non-resilient (or even negatively resilient) because they reduce the absorptive and adaptive capacities of resilience enabled by the market price system.
Social	Very often, grassroots characteristics of communities will enhance the social resilience capacities. It is common that, after a disaster, neighbours will pool their resources and start rebuilding, while undergoing delays in government aid.

3.Conclusion

The concept of vulnerability implies a measure of risk associated with the physical, social and economic aspects and implications resulting from the system's ability to cope with the resulting event. Resilience implies the ability of a system to perform properly even when placed under pressure or the ability of systems to absorb and recover from the impact of disruptive events without fundamental changes in function or structure.

Based on what is required to face disasters, inbuilt features may be inbuilt in the system (design, normal

operation, etc) so as to offer better, if not complete, resilience to the system. As resilience increases, the degree of damage for a given intensity hazard decreases.

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