

Pathology-Informed Approach in Vulnerability Assessment Methods

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- A system pathology is a circumstance, condition, or pattern that acts to limit system performance, or lessen system viability, such that the likelihood of a system achieving performance expectation is reduced. The idea of pathology has been described in multiple fields, including computer science, organizational studies, policy analysis, system-of-systems engineering, and systems engineering. However, there is scarcity of literature describing relationship between system pathology and vulnerability assessment. The aim of this study lies at the intersection of system pathology and vulnerability assessment in engineered systems. First, authors provide the state of the art review of literature on system pathology. Second, authors suggest the utility of pathology-informed approach to vulnerability assessment. The aim is to fuse vulnerability assessment methods with pathology-informed concepts for a more robust approach to vulnerability assessment in complex systems. Any investigation into complex systems, with the goal of understanding and improving the system, begins with formulating the problem. This is also the case when one uses the proposed risk-pathology assessment method. The research leverages on recent developments in the Fukushima Daiichi nuclear disaster to offer insights for assessment and design of critical facilities. Finally, the paper concludes with possible multiple research paths.

Complex System Governance and Pathologies – in a nutshell



All systems are subject to the laws of systems



All systems perform essential governance functions that determine system performance.



Governance functions can experience pathologies in their performance.



Pathologies linked to ‘violation’ of one or more system principles



System performance can be enhanced through purposeful development of governance functions & addressing pathologies

PATHOLOGY

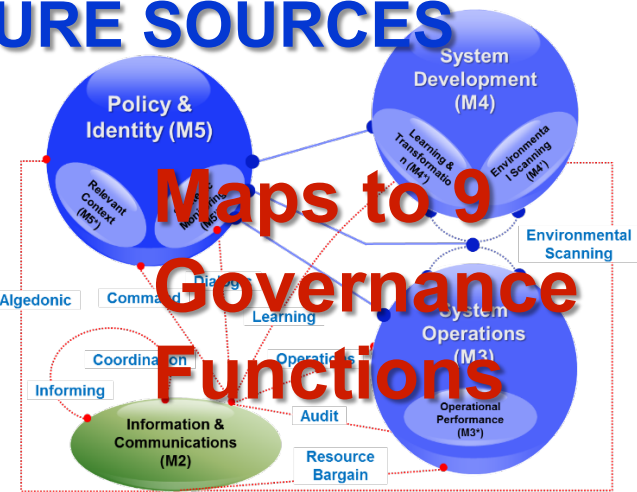
“circumstance, condition, factor, or pattern that acts to limit system performance, or lessen system viability, such that the likelihood of a system achieving performance expectation is reduced” (Keating and Katina, 2012, p. 253)

EXAMPLE

M2.11. Introduction of uncoordinated system changes resulting in excessive oscillation.

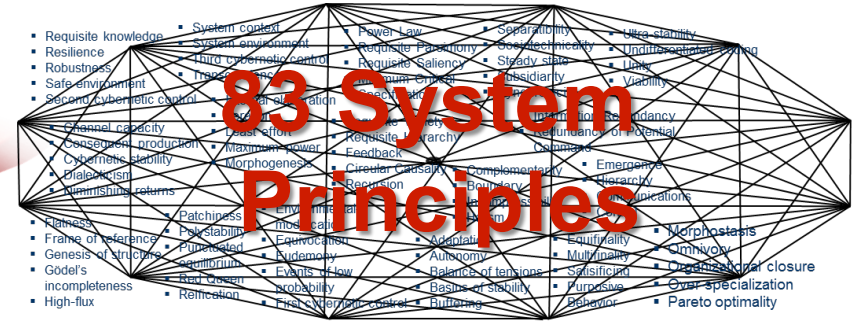


Same underlying system pathology appears as 'different' surface issues



Item	Survey Statement	Recommended Survey General Form
36	M5* 1. Limited accessibility to data necessary to monitor performance.	5* 1 We have access to sufficient information to monitor system performance.
37	M5* 2. [SYSTEM OF INTEREST]-level operational performance indicators are absent.	5* 2 We have an effective set of operational performance indicators.
38	M4 5. Strategic planning/thinking focuses on operations - limited time devoted to strategic analysis.	4.4.2...The crises we encounter are for the most part unavoidable.
39	M4* 1. Limited learning achieved related to operations - limited time devoted to strategic analysis.	4.5 This is taken care of by 4.4.1 and 5.3
40	M4* 1. Limited learning achieved related to operations - limited time devoted to strategic analysis.	4* 1 We effectively respond to shifts in the
41	M5 1. Identity of [SYSTEM OF INTEREST] is ambiguous and does not effectively generate consistency system decision, action, and interpretation.	5.1.1 What makes us unique is clearly understood
42	M5 2. [SYSTEM OF INTEREST] vision, purpose, or values remain unembedded in the operation of the [SYSTEM OF INTEREST].	5.1.2 Our decisions are consistent with our stated purpose
43	M5 3. [SYSTEM OF INTEREST] focus and mission statements focus on unexplored areas.	5.2 Our execution is well aligned with our purpose
44	M5 4. Strategic focus lacks sufficient clarity to direct consistent [SYSTEM OF INTEREST] development.	5.3 Our future development directions are clear.
45	M5 5. [SYSTEM OF INTEREST] identity is not effectively performed.	5.4 We routinely examine our execution for consistency with our stated purpose.
46	M5 6. External [SYSTEM OF INTEREST] protection is not effectively performed.	5.5 Our systems is clearly understood by external entities
47	M5* 1. Incompatible strategy context constraints [SYSTEM OF INTEREST] development.	5* 1 Internally imposed constraints DO NOT overly impact our ability to perform.
48	M5* 2. Lack of strategic [SYSTEM OF INTEREST] monitoring.	5* 2 We take effective actions in response to strategic shifts.
49	M5* 3. Inadequate processing of strategic performance indicators.	5* 3 We have an effective set of strategic performance indicators.
50	M4 1. Lack of forums to foster [SYSTEM OF INTEREST] development and transformation.	4.1 Our forums to direct system development for the future are effective
51	M4 2. Inadequate interpretation and processing of results of environmental scanning - specific, periodic, limited.	4.2 Processes for scanning the environment for potential system impacts is effective.
52	M4 3. Ineffective processing and dissemination of environmental scanning results.	4.3 Shifts in the environment are effectively communicated throughout the system.
53	M4 4. Long-range strategic development is sacrificed for management of day-to-day	4.4.1 We devote a sufficient amount of our resources to future development.

53 Complex System Pathologies



83 System Principles



Thinking About Pathologies

➔ **System Pathology** – “A circumstance, condition, factor, or pattern that acts to limit system performance, or lessen system viability, such that the likelihood of a system achieving performance expectations is reduced.” (Keating & Katina, 2012, p. 253)

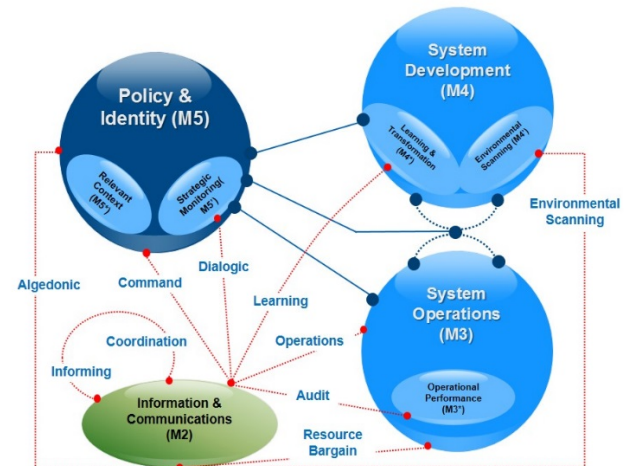
➔ **Complex System Governance Reference Model** – guides pathology assessment (Keating, et al. 2015)

System principle and primary proponent	Brief description	Strain
Communication (Shannon, 1948a, 1948b)	In communication, the amount of information is defined, in the simplest cases, to be measured by the logarithm of the number of available choices. Because most choices are binary, the unit of information is the bit, or binary digit.	Communication process interpretation: 1 through the me 2 between the m 3 between the m 4 between the m the metasystem
Control (Checkland, 1993)	The process by means of which a whole entity retains its identity and/or performance under changing circumstances.	Control for a system elements within the highest levels of an establishment of pe independence of el and provide integra system performanc
Emergence (Aristotle, 2002)	Whole entities exhibit properties which are meaningful only when attributed to the whole, not its parts – e.g., the smell of ammonia. Every model of systems exhibits properties as a whole entity which derive from its component activities and their structure, but cannot be reduced to them (Checkland, 1993).	For systems of syst that cannot be know about over time wi to assume system c will necessarily yie
Hierarchy (Pattée, 1973)	Entities meaningfully treated as wholes are built up of smaller entities which are themselves wholes – and so on. In a hierarchy, emergent properties denote the levels (Checkland, 1993).	The system of syst nature. It is impera roles, authorities, a maintained on an o
Complementarity (Bohr, 1928)	Two different perspectives or model system will reveal truths regarding a system that are neither entirely inde use entirely compatible.	



Table 2 System of systems pathologies related to metasystem functions (continued)

Metasystem function	Nature of potential system of systems pathologies
Subsystem 4 Development	S4.1 Lack of forums to foster system development and transformation
	S4.2 Environmental scanning, interpretation, and processing are non-existent, sporadic, or limited in nature
	S4.3 Absence of system representations or models to guide analysis
	S4.4 Processing and dissemination of environmental scanning results inconsistent or ineffective
	S4.5 Long range strategic development is sacrificed for management of day to day operations – limited time devoted to strategic analysis
	S4.6 Strategic planning/thinking focuses on operational level planning and improvement
Subsystem 4* Learning and transformation	S4*.1 Limited learning achieved related to environmental shifts
	S4*.2 Integrated strategic transformation not conducted, limited, or ineffective
	S4*.3 Design for system learning informal, non-existent, or ineffective
Subsystem 5 Identity	S5.1 Identity of system is ambiguous and does not effectively generate consistency system decision, action, and interpretation
	S5.2 System vision, purpose, mission, or values remain unarticulated, or articulated but not embedded in the execution of the system
	S5.3 Balance between short-term operational focus and long-term strategic focus is unexplored or lacks ability to guide decisions related to resource allocation

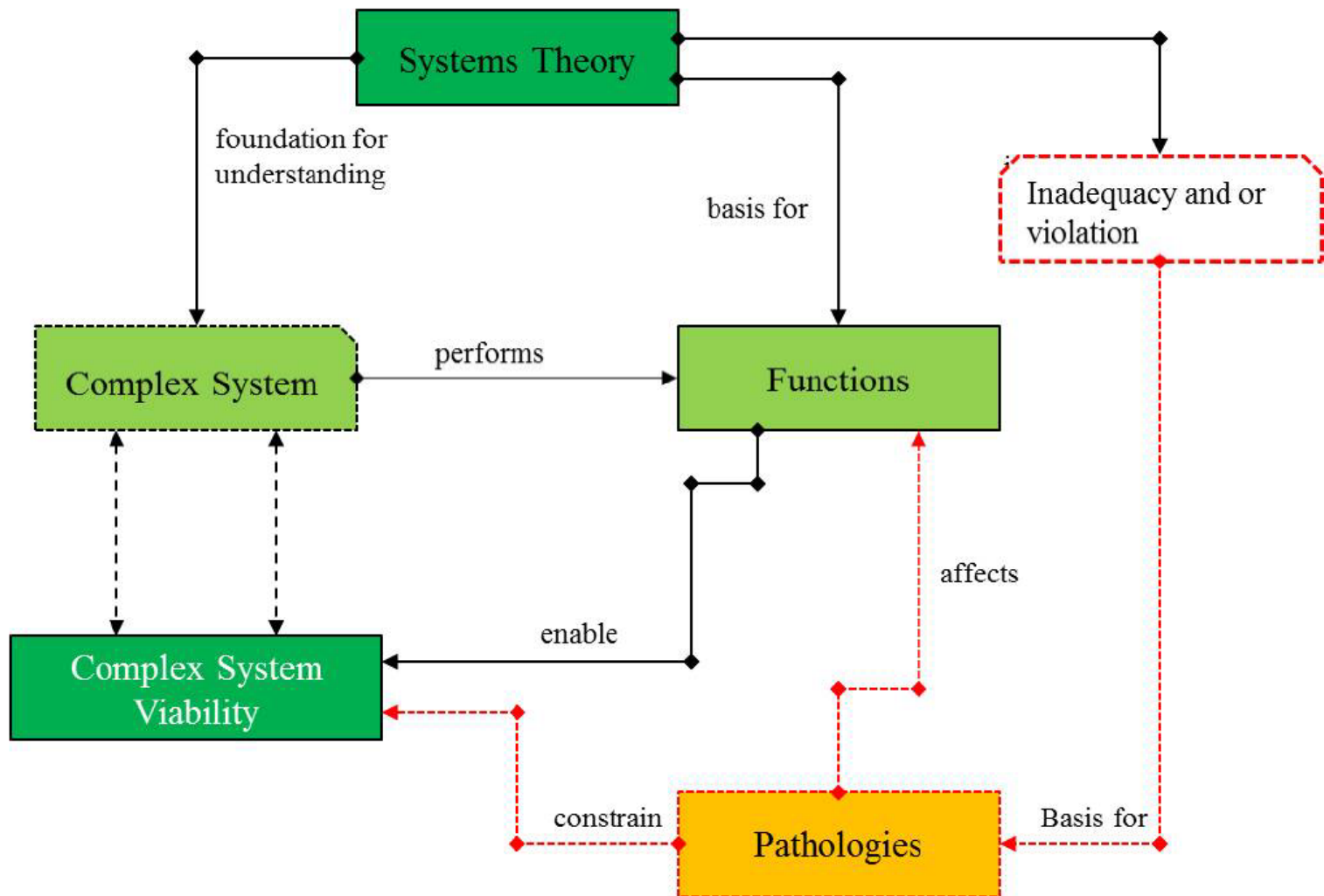


Keating, C.B. and Katina, P.F. (2012) ‘Prevalence of pathologies in systems of systems’, *Int. J. System of Systems Engineering*, Vol. 3, Nos. 3/4, pp.243–267.



Thinking About Pathologies

Figure 2 An emerging perspective of systems theory-based pathologies (see online version for colours)



VULNERABILITY AND ITS ASSESSMENT

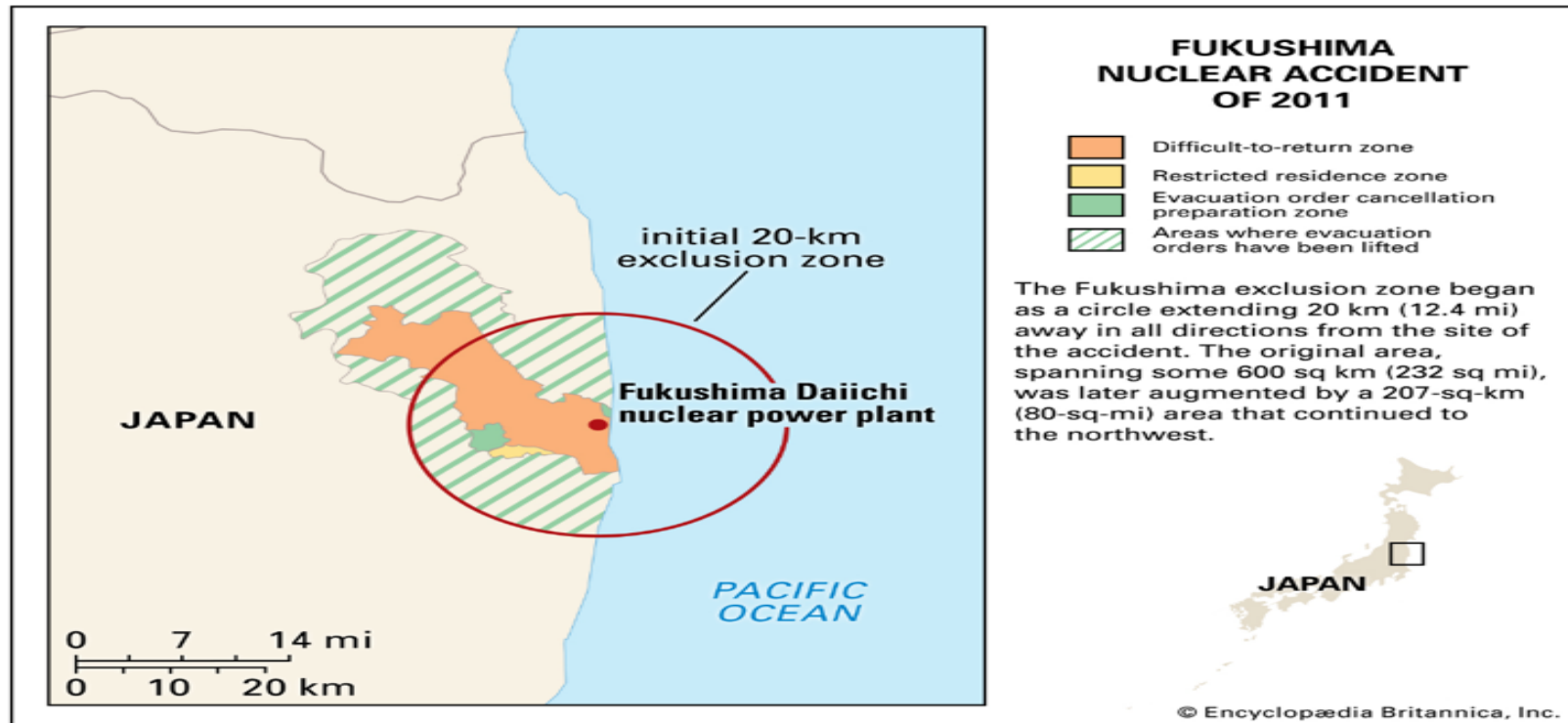
- In summary, regardless of diverging perspectives definitions of vulnerability, there is consensus on the need to consider vulnerability during system assessment. If one adopts vulnerability as “inherent characteristics of a system that create the potential for harm but are independent of the risk of occurrence of any particular hazard” [28, p. 19], then there emerges a need for consideration of the inherent nature of the system and stressors that could affect the system. It is at this consideration that system pathologies might be used to enhance vulnerability assessment methods.

- There is no shortage of methods and tools to assist in vulnerability assessment [31]. Vulnerability assessment methods include and not limited to, Econometric Methods which include *Vulnerability as Expected Poverty* (VEP), *Vulnerability as Expected Utility* (VEU), and *Vulnerability as Uninsured Exposure to Risk* (VER), *Household Economy Approach* (HEA), *Household Livelihood Security Analysis* (HLSA), *Household Vulnerability Index* (HVI), *Individual Household Model* (IHM),
- *Participatory Vulnerability Analysis* (PVA) and *Participatory Capacity and Vulnerability Analysis* (PVCA), *Participatory Wealth/Well-being Ranking* (PWR), Poverty Measures: *Poverty Assessment Tools* (PAT) and the *Progress out of Poverty Index* (PPI), and *Southern Africa Vulnerability Initiative* (SAVI) Framework, just to name a few. Beyond the need to know the advantages and disadvantages of each method, the selection and usage of a vulnerability assessment method must depend on the context of the problem of interest and capability of the method.

- One of the widely used methods is Hierarchical Holographic Vulnerability Assessment (HHVA). HHM has its roots in Hierarchical Holographic Modeling (HHM), which is used in stepwise approach within the framework of parsing the vulnerability concept, hazards and accident scenarios identification, and vulnerability management [32]. The proposed framework can serve as generic vulnerability assessment.
- The goal and the overview of HHVA can be summarized as: (a) a way to better understand the system, its elements, and their interdependencies, (b) holistically identify hazards (threats) the system could expose to, (c) systematically point out and assess vulnerabilities, (d) develop policy options against these vulnerabilities, and (d) filter, ranking and recommend policy options. HHVA has nine phases and these are articulated elsewhere [23,28].

PATHOLOGY-INFORMED VULNERABILITY ASSESSMENT:

The Case for Fukushima Daiichi Nuclear Disaster



- A mapping of pathology-informed vulnerability assessment can be used to provide an interesting perspective. Granted, this mapping is after the fact. Nonetheless, the pathologies associated with different functions provide a glimpse into potential failure modes that could affect design of such systems that is beyond the technical specifications. This is supported by official findings conducted to investigate the Fukushima accident (e.g., see Fukushima Nuclear Accident Analysis Report [34]). Prior safety concerns suggest there was a culture of ignoring safety concerns involving layout of emergency cooling system (e.g., the original plans separated the piping systems for two reactors in the isolation condenser from each other. However, the application for approval of the construction plan showed the two piping systems connected outside the reactor.

- The changes were never noted; a clear violation of regulations), lack of consideration for flooding (e.g., there is evident suggesting that one of two backup generators of Reactor 1 failed, after flooding in the reactor's basement in October 1991 as well as a lack of consideration of employee concerns), lack of consideration of several studies warning of effects of possible Tsunami, and well as a lack of consideration of earthquake vulnerability (e.g., at a 2008 meeting of the G8's Nuclear Safety and Security Group in Tokyo, experts warned that a strong earthquake with a magnitude above 7.0 could pose a 'serious problem' for Japan's nuclear power stations).

- These issues are pathological in nature and review assessment at a different local level. A pathology-informed vulnerability assessment suggests examining pathologies at policy and identity, system context, strategic monitoring, system development, learning and transformation, environmental scanning, system operations, operational performance, and communication (and information) as potential issues that could affect system performance.

CONCLUSION

- A system pathology is a circumstance, condition, factor, or pattern that acts to limit system performance, or lessen system viability, such that the likelihood of a system achieving performance expectation is reduced [1]. While the term 'pathology' has its roots in the field of medicine, with the concern to logia (the study of) and pathos (suffering, experiencing, and emotions) in animate organisms, recent research indicates wide acceptance in several disciplines, including computer science, intelligent-based systems, organizational studies, policy analysis, system-of-systems engineering, and systems engineering.
- In this study, we extend pathology to vulnerability assessment by incorporating system pathologies in assessment of issues that affect system performance. This approach calls for adoption of system pathology and their assessment in system vulnerability approaches. The M-Path Method and HHMA are presented as complementary, guiding in the identification of pathologies, beyond technical failures that can affect system performance.

- The deployment of M-Path Method in different venues can also serve a dual-role beyond identification and development of responsive strategic actions to deal with pathologies. First, the more the method is utilized in field applications, the more refined the method becomes. In essence, certain elements of the method might need to be modified based on feedback from field applications. This might be for local application or perhaps to the more general structure and deployment of the methodology. Second, over time patterns of pathologies might emerge. It is possible that certain kinds of pathologies might be associated with certain organizations or circumstances. However, the further development of the method is predicated on field applications to provide continuing development. Subsequently, this might offer insights into the nature of effective and ineffective strategies in response to pathologies in organizations.