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)

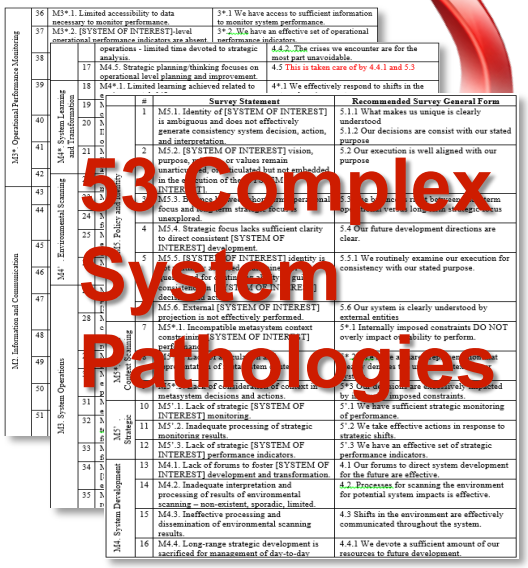
EXAMPLE

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

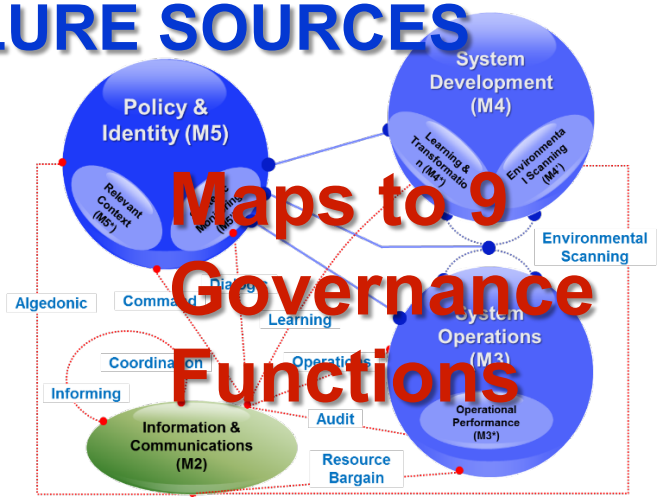
Keating, C. B., & Katina, P. F. (2012). Prevalence of pathologies in systems of systems. *International Journal of System of Systems Engineering*, 3(3-4), 243-267.

Same underlying system pathology appears as 'different' surface issues

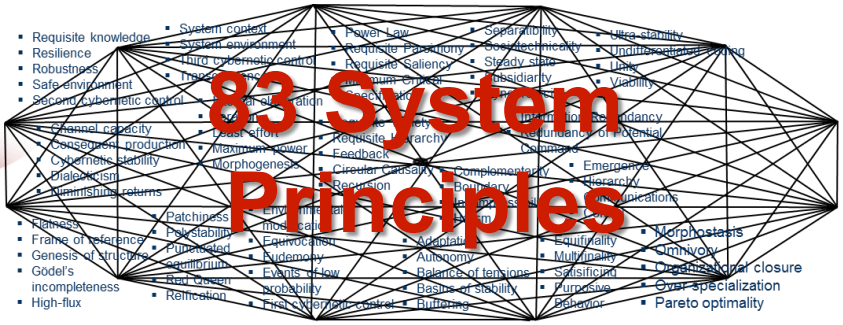
53 Complex System Pathologies



Maps to 9 Governance Functions

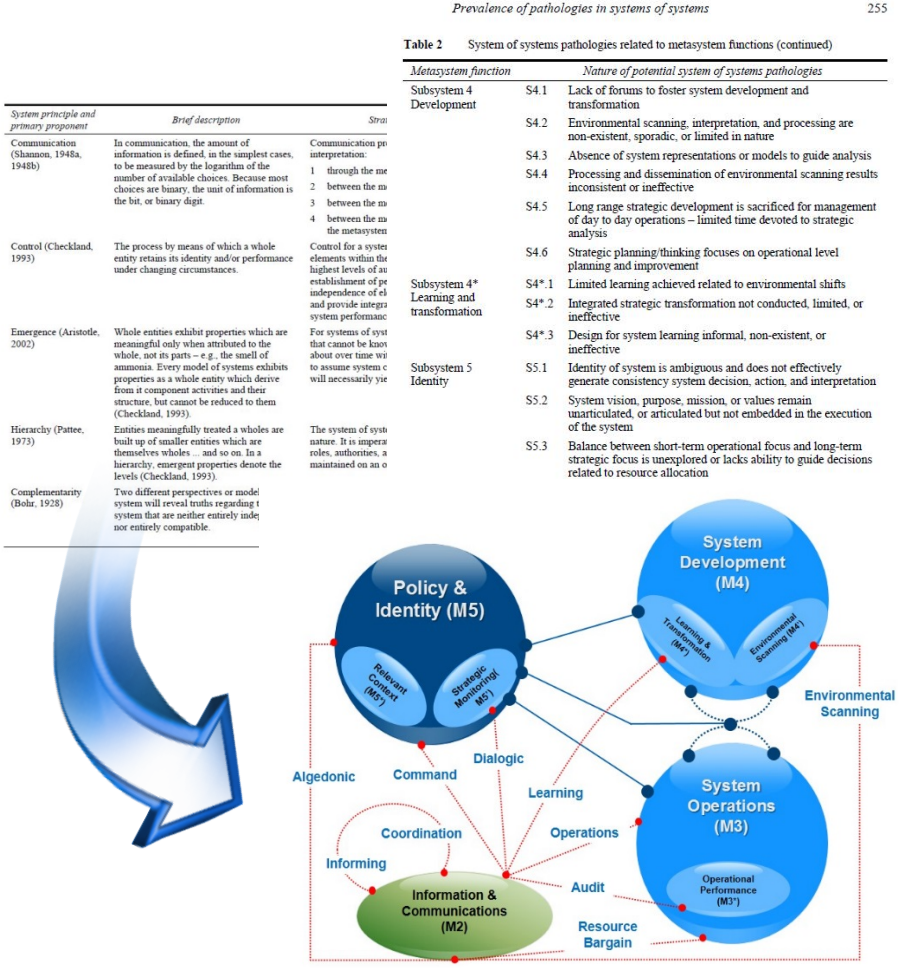


83 System Principles



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)



Prevalence of pathologies in systems of systems 255

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.

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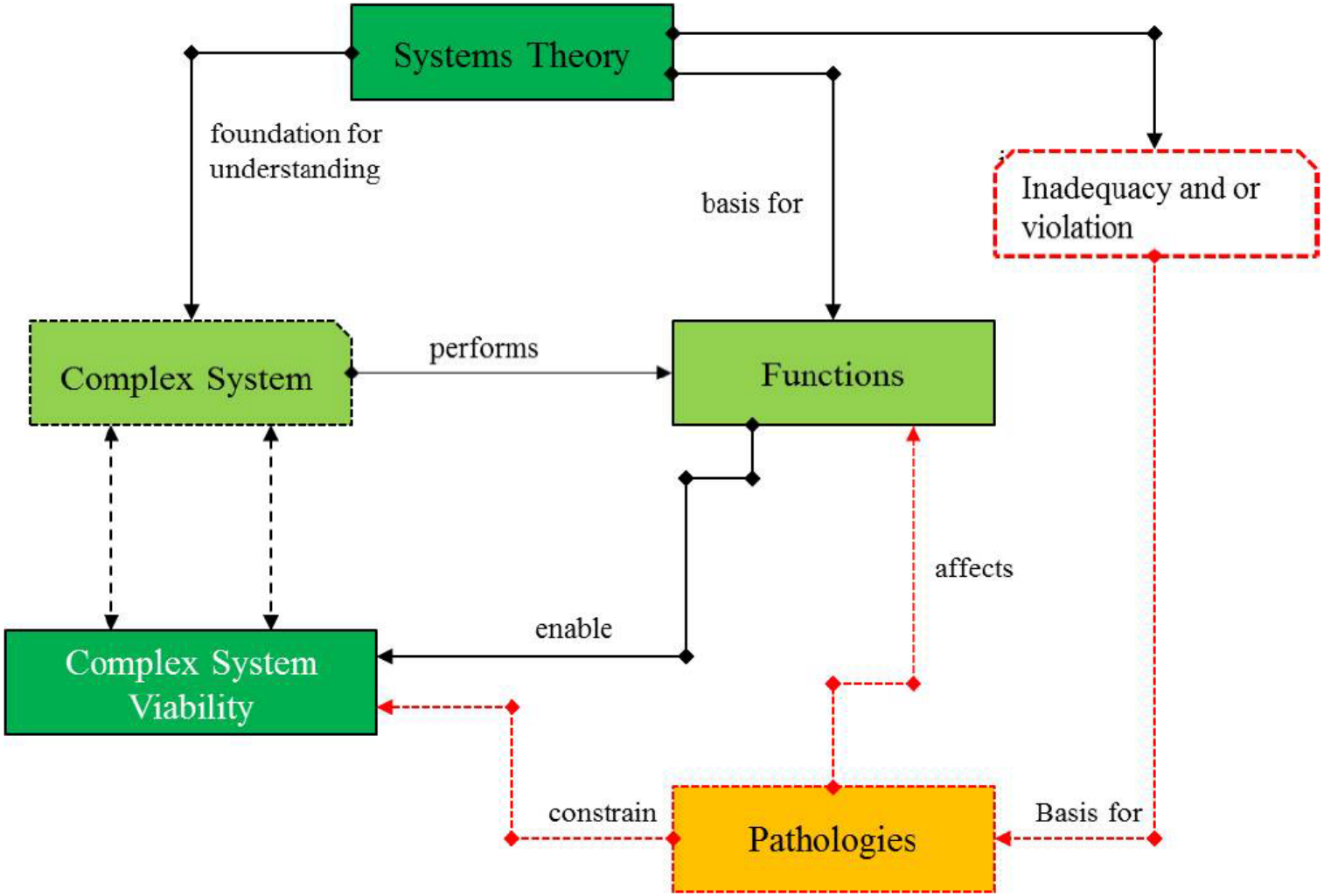
Thinking About Pathologies

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



From Katina, P.F. (2015). 'Emerging systems theory-based pathologies for governance of complex systems', *Int. J. System of Systems Engineering*, Vol. 6, Nos. 1/2, pp.144–159.

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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.

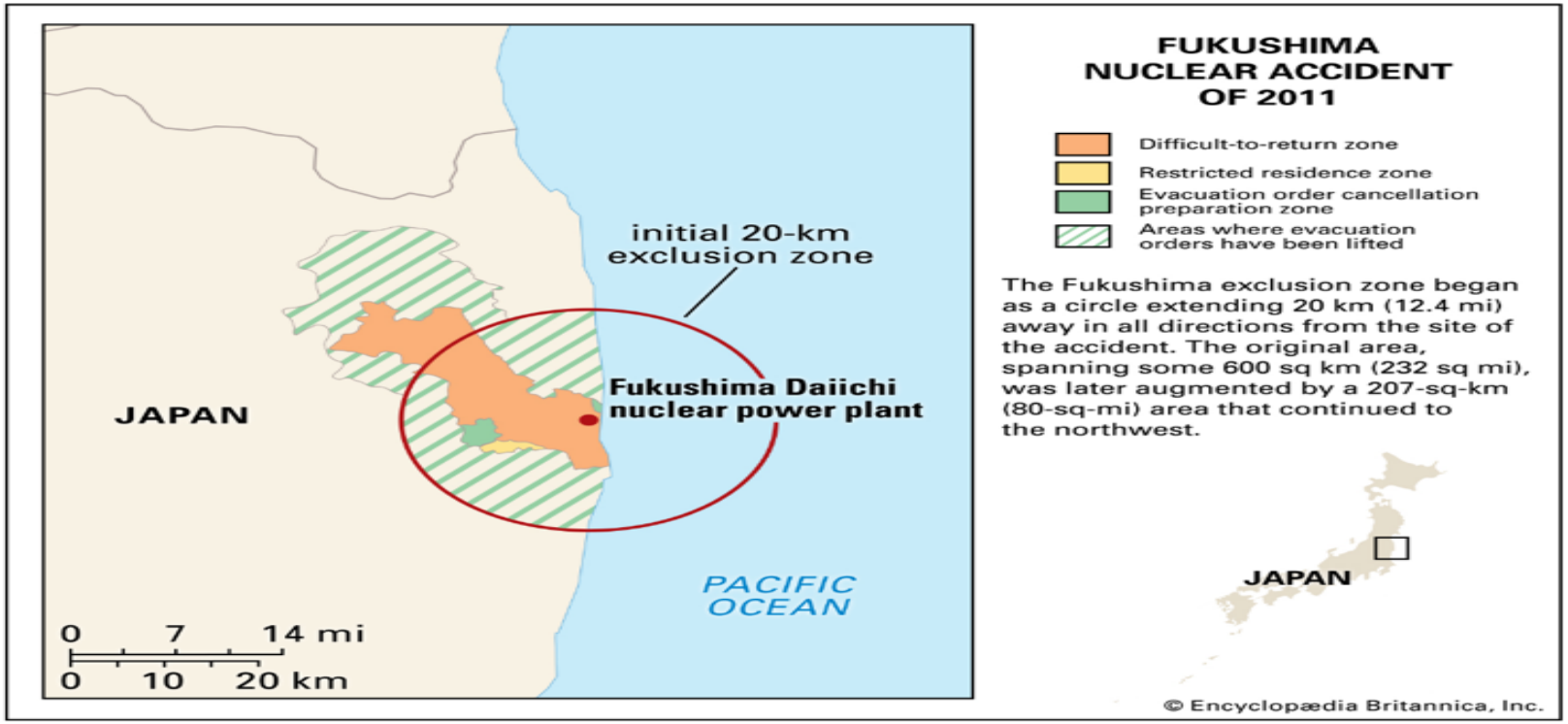
- There is no shortage of methods and tools to assist in vulnerability assessment [31]. Vulnerability assessment methods include and not limited to, Econometric Methods which include *Vulnerability as Expected Poverty* (VEP), *Vulnerability as Expected Utility* (VEU), and *Vulnerability as Uninsured 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 Tool*s (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



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- 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 investing 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 acceptable 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.