The Stress-Strain Model of Resilience Operationalizes the Four Cornerstones of Resilience Engineering

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Abstract. This paper presents the latest results on the Stress-Strain model of resilience and shows how the model provides a means to operationalize the four cornerstones of Resilience Engineering as proposed by Hollnagel and utilized in the Resilience Analysis Grid. The Stress-Strain model of resilience, originally proposed by Woods and Wreathall in 2006, addresses one of the original goals for Resilience Engineering -- how to assess brittleness of an organization or system. The model is based on a representation, in the tradition of plots of adaptive landscapes, that captures the relationship of demands or challenge events (what variations and events place stress on the system) and the ability of the system to draw on sources of adaptive capacity to respond to challenge events. The Stress-Strain model provides a framework for analysis to answer the key question -- how does a system stretch to handle surprises?

1 INTRODUCTION

One major family of approaches to Resilience Engineering defines resilience as the opposite of brittleness, or how to bring 'extra' adaptive capacity to bear in the face of potential for surprise (Woods, 2005; 2006). This approach juxtaposes brittleness versus graceful degradation and bases analysis of systems on the question: ***how do systems stretch to handle surprises***. Without some capability to continue to stretch in the face of events that challenge boundaries, systems are more brittle than stakeholders realize. And all systems, however successful, have boundaries and experience events that fall

outside these boundaries - surprises. Being prepared to adapt to handle surprise arises because there is always some rate and kind of events that occur to challenge the boundaries of more or less optimal. or more or less robust performance. Ironically, attempts to expand this envelope of base adaptive capacity (or competence envelope) shifts the kinds of events and the dynamics of events that will occur to challenge the new boundaries.

The field of Resilience Engineering needs to provide integrative models that can be used to analyze and track how an organization is functioning as an adaptive system. The Stress-Strain model of resilience (Woods and Wreathall; 2006; 2008) is one and is arguably the most complete. All of the key concepts, including the basic trade-offs (Woods, 2006; Hollnagel, 2009; Hoffman and Woods, 2011) and the four cornerstones of Resilience Engineering as proposed by Hollnagel (2008) and utilized in the Resilience Analysis Grid (Hollnagel, 2011) -- can be expressed in the notation and visualization the Stress-Strain model provides. The framework specifies anticipatory monitoring focused on the boundary area in the adaptive landscape, three forms of adaptive capacity to be called into action when events challenge boundaries, and two learning processes that should go on in parallel after organizations experience an adaptive shortfall. The Stress-Strain Model also provides a visualization for generating and tracking data about how an organization performs the four cornerstones of Resilience Engineering.

In the tradition of plots of adaptive landscapes (e.g., McGhee, 2007), the Stress-Strain model provides a representation that captures the relationship of demands or challenge events (what variations and events place stress on the system) and the ability of the system to respond to challenge events (Figures 1 and 2). As a landscape, the Stress-Strain model for a particular organization captures the split between its *base and extra* adaptive capacities and the potential for *adaptive shortfalls* to arise where responses cannot match the demands of challenge events that fall near or beyond the boundary area of the base envelope (*the borderlands*). The plot then captures how the system in question brings to bear extra adaptive capacity to handle events near or outside the boundaries of 'normal' functioning and allows systems to continue to respond to changing demands and meet some goals to some degree. The analysis shows how a system is capable, in advance, to handle classes of surprises or challenges (e.g., Finkel, 2011). Sources of resilience undergird this capability and providing and sustaining these sources has its own difficulties that arise from the need to manage fundamental trade-offs. This paper shows how the latest results on the stress-strain model of resilience provide a means to operationalize the four cornerstones of Resilience Engineering (Hollnagel, 2008).

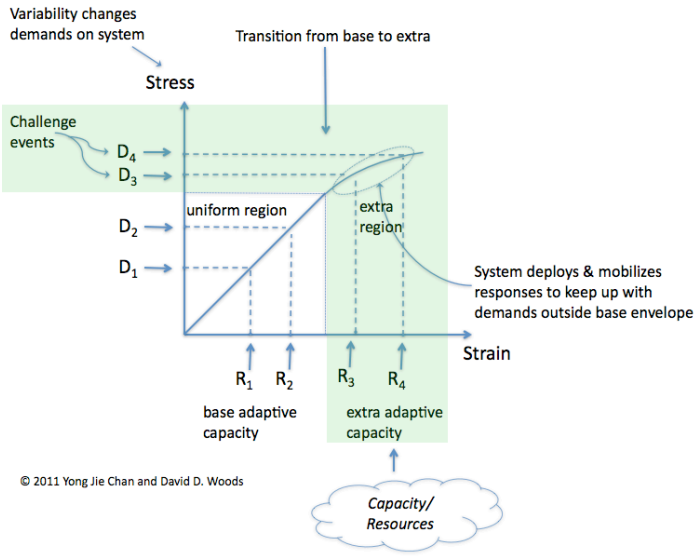

Figure 1. Adaptive Landscape Representation of the Stress-Strain Model. Basics of Notation: Demand/Response relationship defines fitness; Base and Extra Adaptive Capacities regions are delineated.

2 OPERATIONALIZING THE FOUR CORNERSTONES

2.1 The Cornerstones of Anticipation and Monitoring

One fundamental finding is that resilience (defined as stretching at and beyond boundaries) is based on the ability to anticipate potential bottlenecks or shortfalls ahead. Limits on the ability to do this means the system risks falling into one of the basic patterns of how adaptive systems fail. In particular, the ability to anticipate potential bottlenecks or shortfalls ahead is related to how a system exhausts its capacity to respond as challenges cascade or build -- as defined in the decompensation pattern of adaptive system failure (Cook and Rasmussen, 2005; Woods and Branlat, 2011).

The need to anticipate in order to keep up with changing patterns of demands and challenges provides a way to focus an organization's monitoring resources at the *borderlands* (Figure 2) between the organization's *base adaptive capacity* and its ability to *bring extra adaptive capacity to bear* to stretch performance in the face of smaller or larger surprises (see Woods, in preparation). Monitoring at the borderlands in an

adaptive landscape representation of an organization's base and extra adaptive capacity provides a means to understand potential adaptive shortfalls.

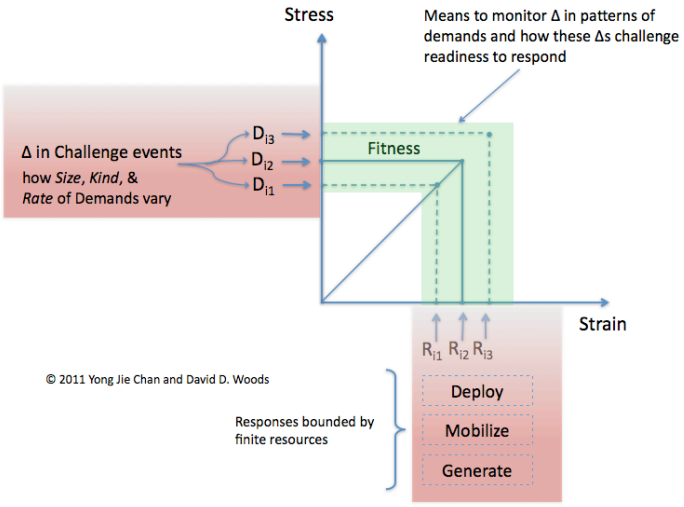

Figure 2. Monitoring the Boundary area between Base and Extra Adaptive Capacities. This is a transition region since the boundary is neither crisp nor well understood (shaded area represents 'Borderlands' in the Fitness space). In the borderlands the potential for surprise (challenge events or variations that fall outside base capacity) could generate adaptive shortfalls (breakdowns in the ability to deploy/mobilize/ generate responses to meet those challenges). The stress-strain landscape represents fitness as the ability to deploy, mobilize, or generate responses to keep up with changing patterns of demands.

2.2 The Cornerstone of Responding

One of the cornerstones is -- Responding. The stress-strain model operationalizes this in terms of three processes -- how does the system *deploy, mobilize, and generate* responses to stretch to keep up with changing demands (Figure 2). Each of the three operates at different time scales and is poised to match resources (and therefore resource costs) to the expected rate of surprise. Settings with high expected experience of surprise (e.g., the emergency department or urban fire fighting) invest resources to

be able to deploy extra adaptive capacity rapidly as situations present and cascade. Lower rates of experience of surprise may lead an organization to prepare to be able to mobilize resources to produce the needed capabilities to match challenge events (e.g., how hospitals in an area plan and prepare to handle mass casualty events such as the Aurora CO shooting victims). When the ability to track the shape of surprises to come is low, an organization may invest in the ability to generate new kinds of capabilities to match new kinds of challenges which are unanticipateable in advance while at the same time it is certain that future challenges will not match current base adaptive capabilities and even current capabilities to deploy extra adaptive capacity (Cook and Nemeth, 2006; or see the 1940 case of how George Marshall prepared the US Army officer core for the demands of future operations - Ricks, 2012).

2.3 The Cornerstone of Learning

Another of the cornerstones is -- Learning. The stress-strain model operationalizes this in terms of two parallel learning processes or loops. One learning loop concerns how the organization learns to *expand base adaptive capacity* given how it experiences an adaptive shortfall event and defines the experience of that shortfall (Figure 3). The very same experience of an adaptive shortfall event should also trigger a parallel learning loop that examines how extra adaptive capacity was brought to bear to try to continue to stretch function despite the shortfall (Figure 4). This learning loop looks at re-calibrating distant perspectives to better understand the shape of surprise in the borderlands, what the system actually draws on as sources of resilience when stretching at the borderlands, and the limits revealed about the ability to deploy or mobilize extra adaptive capacity for future challenge events. The two learning processes go on in parallel after organizations experience an adaptive shortfall. Supporting both learning loops is critical to avoid the situation where an organization can undermine, inadvertently over time, their own sources of resilience (e.g., as in the lead up to the Columbia accident) and inadvertently reinforce the risk of falling into one of the three basic patterns of adaptive system failure (Woods and Branlat, 2011).

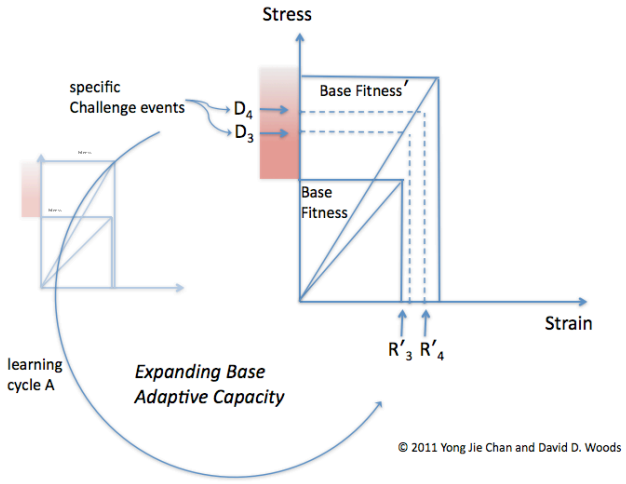

Figure 3. Learning from Specific Surprises: Cycle A - Expanding Base Adaptive Capacity. Specific surprise events should trigger learning and change. In the figure specific new demands have been recognized outside previous base capacity, and new responses added to the base of plans to meet those new demands. Note, the new response capability, in this case, required new resource investments.

3 SUMMARY

The Stress-Strain Model operationalizes the four cornerstones as:

• Monitoring at the borderlands in an adaptive landscape representation of an organization's base and extra adaptive capacity provides a means to understand potential *adaptive shortfalls*.

• Responding to kinds of surprise events, which are experienced as adaptive shortfalls, calls into action extra adaptive capacity. How extra capacities were *deployed or mobilized* provides a means to understand what capabilities need to be resourced and sustained to handle future surprise events.

• Learning from the experience of a smaller or larger, more or less critical adaptive shortfalls can lead to *reframing of models* of (a) actual base adaptive capacity, (b) the

changing shape of surprise at the borderlands, and (c) reveals how extra adaptive capacity is brought to bear.

• Anticipation of risks of adaptive shortfalls and adaptive failures comes from feedback on the above three, in combination.

The Stress-Strain Model, as a kind of representation of an adaptive landscape, then provides a visualization for generating and tracking data about how an organization performs the four cornerstones of resilience engineering.

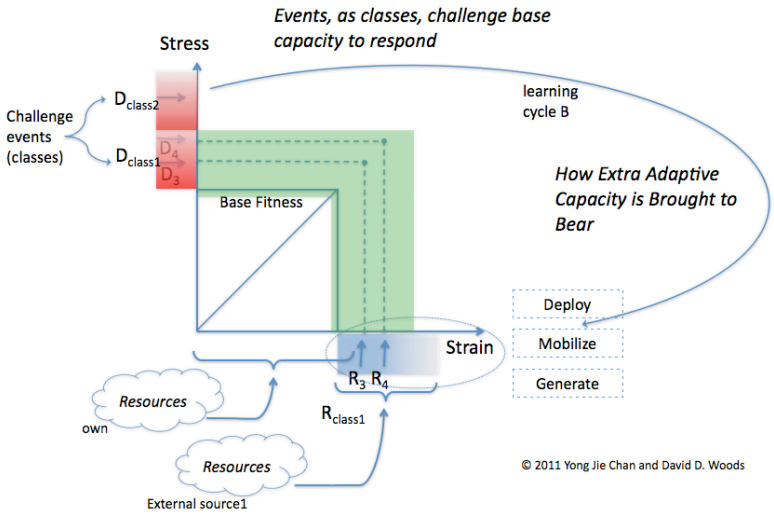

Figure 4. Learning from The Shape of Surprise: Cycle B - How Extra Adaptive Capacity is Brought to Bear To Stretch To Accomodate Changing Demand. Responses to past challenges in the borderlands informs assessment of how the system brings extra adaptive capacity to bear relative to classes of challenges. This provides the basis to re-examine how the system develops, enhances, and sustains the ability to bring extra adaptive capacity to bear to handle surprise.

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