Applying Systems Thinking to Coastal Infrastructure Systems

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Applying Systems Thinking to Coastal Infrastructure Systems

David A. Pezza and C. Ariel Pinto
Objectives

• Explore how to represent the coast as system.
• How to apply systems thinking to coastal infrastructure.
• Offer a framework to employ an integrated systems approach.
Representing the Coast as a System

- Quantify, communicate, and manage risk
- Employ an integrated systems approach
- Exercise sound leadership, management, and stewardship in decision making processes, and
- Adapt critical infrastructure in response to dynamic conditions and practice.

(ASCE, 2009, p.14)
Rising Seas

“It is change, continuing change, inevitable change, that is the dominant factor in society today. No sensible decision can be made any longer without taking into account not only the world as it is, but the world as it will be.” Sir Isaac Asimov, 1982 (p.29)

Founding of Jamestown

**Figure 1: Projected Global Sea Level Rise, 1992-2100**

Local Sea Level Rise Projections

Utilizing these global sea level rise projections for local planning purposes requires adjusting the historic rate of sea level rise to account for vertical land movement. The U.S. Army Corps of Engineers (ACOE), which has a policy of considering sea level rise in its civil works projects, uses a rate of 2.61 mm/year as the subsidence value for Norfolk, which results in a total historic relative sea level rise rate of approximately 4.3 mm/year (U.S. Army Corps of Engineers n.d.).

The values and curves developed using the ACOE’s local rate with the global sea level rise scenarios are shown in Table 2 and Figure 3. This chart also incorporates the long-term historic observations, including both monthly and average mean sea level trends. This observational data was obtained from the Permanent Service for Mean Sea Level (Permanent Service for Mean Sea Level n.d.). These curves can be used to develop time-based sea level rise exposure maps for the Hampton Roads region. An example of this exercise is discussed later in this...
Representing an Integrated Coastal System

An Enterprise System

A Network

An Enterprise Systems Approach

• It represents a democratic society where no single entity is in control.
• It is structured as a network where all points are linked.
• Its behavior is emergent, that is its properties are unknown in advance and only evident as the network interacts.
• Capable of adaptation to change

A network of interdependent people, processes and supporting technology not fully under control of any single entity (Mitre, 2007).
Figure 1 Transformation from Network to Hierarchy

Lawson, 2005
Figure 2 Hierarchical Structure of Local Infrastructure Systems

Tier 1 – The Community

Tier 2 (a, b & c) – Network of Multiple Subsystems

Tier 2 c – Specific Subsystems

Tier 3 – Local Jurisdictions

Pezza and Pinto (2018)
Systems Thinking

- **Mechanics** – Traditional Modeling (quantitative)
- **Context** – Non-traditional Modeling (qualitative)
- **Emergence** – Design for extreme uncertainty, interrelationships, influence and paradigm shifts

**The Dilemma** – a predicament that defies a satisfactory solution.

Keating, Slide 400 (2014)-modified
An Example of a Dilemma

The best technical solution to a design may very well not be the best overall solution (Allen et al., 2004)
Table 1 The Nature of a Problem Situation

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Traditional Problem</th>
<th>Unique Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Type</td>
<td>Complicated</td>
<td>Complex</td>
</tr>
<tr>
<td>Quantifiable</td>
<td>Yes</td>
<td>Not Easily</td>
</tr>
<tr>
<td>Structure</td>
<td>Understood</td>
<td>Emergent</td>
</tr>
<tr>
<td>Approach</td>
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<td>Not Evident</td>
</tr>
<tr>
<td>Definition</td>
<td>Clear</td>
<td>Ambiguous</td>
</tr>
<tr>
<td>Environment</td>
<td>More Static</td>
<td>More Dynamic and Turbulent</td>
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<tr>
<td>Boundaries</td>
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Complicated Systems

- Complicated systems can have many pieces, where each component is understood in isolation and the whole can be reassembled from its parts such as many mechanical systems.
- These pieces work as one system to accomplish its function, but one key defect can stop the function.
- Also, complicated technical systems lack the ability to adapt. Such systems require redundant or backup components to mitigate failure.

(Ottino, 2004)
Complex Systems

- Situations where human participation or judgment is a key component, reductionist methods can misrepresent the problem domain.
- The human aspect introduces relationships between stakeholders as well as complexities not easily represented by hard systems methodologies.
- These kinds of problems require decision makers to account for both the technical factors and the needs of stakeholders to achieve sustainable results.

(Kirk, 1995)
Stakeholders’ *Worldview*
Frame the Nature of the Problem

It is important for stakeholders to have a Common worldview.

It is at Tier 1 in Figure 2, the level of governance, where agreements are made to bring together the resources needed to Adapt to rapid change.
Types of Errors

A Type III error is solving the wrong problem precisely in the most efficient way possible. This is often caused by having the wrong stakeholders involved or letting biases shape the problem definition.

A Type IV error is engaging in “muddled” thinking that is typically caused by a philosophical mismatch among stakeholders such that agreement is unlikely and movement to resolution is highly improbable.

(World Economic Forum 2011, Keating, 2008)
Systems Analysis

Figure 3
Influence of Social Component

# Hard Systems Thinking

## Table 1 Nature of a Problem

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Keating (2014)

## Technical Problem

- Technology
- Org/Mgr Policy
- Political
- Human

Influence of Social Component (Context)
- Context
- Human Elements
- Political Elements
- Organizational, Managerial, & Policy Elements
- Degree and Speed of Connectivity

Optimized Solutions
## Soft Systems Thinking

### Table 1 Nature of a Problem

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### Socio-Technical Problem

Satisficing Solution – an acceptable solution, while not optimal, it is good enough.

Keating (2014)
The Conundrum – How do you judge?

- Optimization most compatible with complicated engineering solutions
- Satisficing solution is more compatible with complex engineering solutions.
Complexity Theory

Stacey’s Zones of Complexity

Stacey (2011)
**Figure 4 The Zones of Complexity**

**Agreement vs Certainty**

**Table 2 Constructed Scale**

A: Can predict the potential hazard with a degree of confidence

B: Can only represent the potential hazards with planning scenarios.

C: Unable to represent the potential hazards in any scientifically based format.

1. There is an agreed upon solution(s), schedule and the financial capacity to implement resiliency.

2. There is an alignment of Federal, State and local jurisdictions in the form of a signed partnership agreement.

3. There is no regional or state representation with authority that can serve as sponsor with Federal government.

Pezza and Pinto (TBD)
Systems Methodology

Ackoff’s Interactive Planning

• The interactive planning objective “is directed at creating the future.
• It is based on the belief that an organization’s future depends at least as much on what it does between now and then, as on what is done to it.
• Therefore, this type of planning consists of the design of a desirable present and the selection or invention of ways of approximating it as closely as possible. It creates its future by continuously closing the gap between where it is at any moment of time to where it would most like to be.

Approach has three underlying principles
• Participation – The stakeholders must lead the process and not leave it to outside experts.
• Continuity – Stakeholders should plan for emergence, i.e., unanticipated changes characteristic of complex problems only evident as the problems unfold.
• Holism – Stakeholders should plan across and down the hierarchical tiers to seek agreement in the worldview to avoid Type IV error.

(Ackoff, 2001)
A Framework for Systems Thinking

Table 3 Classification of System

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Simple system Apply hard system thinking</th>
<th>Complex system Apply soft systems thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stacey's zones</td>
<td>Dark green, a hard systems approach.</td>
<td>Yellow or red, a soft systems approach.</td>
</tr>
<tr>
<td>Number of elements</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Interactions between elements</td>
<td>Few</td>
<td>Many</td>
</tr>
<tr>
<td>Predetermined attributes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Interaction organization</td>
<td>Highly organized</td>
<td>Loosely organized</td>
</tr>
<tr>
<td>Laws governing behavior</td>
<td>Well defined; deterministic or stochastic methods</td>
<td>Undefined; emergence behavior</td>
</tr>
<tr>
<td>System evolution over time</td>
<td>Not evolve</td>
<td>Evolves</td>
</tr>
<tr>
<td>Subsystems pursue own goals</td>
<td>No</td>
<td>Yes (purposeful)</td>
</tr>
<tr>
<td>System affected by behavioral influences</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Predominantly closed or open to the environment</td>
<td>Largely closed</td>
<td>Largely open</td>
</tr>
<tr>
<td>Predictable</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Method of analysis</td>
<td>Risk-resilience-informed decisions</td>
<td>Interactive planning</td>
</tr>
<tr>
<td>Type decision</td>
<td>Risk-resilience-informed decisions</td>
<td>Satisficing solutions</td>
</tr>
</tbody>
</table>

Figure 4

Figure 5 Systems Methodology Flow Chart
Example 1 Socio-Technical Problem

**Figure 2**

1. Coastal Community
   - 2a. Subsystems Infrastructure
     - 2b. Energy
     - 2b. Water
     - 2b. Waste
     - 2b. Transport
     - 2b. Landscape
     - 2b. Information
   - 2c. Regional authority for collecting and treating wastewater from local jurisdictions

**Figure 4**

- Edge of Chaos
- Zone of Chaos
- Zone of Complexity
- Close to Agreement
- Far from Agreement

**Figure 5**

- Type Problem Situation
  - Green Zones
    - Table 2
    - Complicated, Apply Hard Systems Thinking Table 3
  - Mathematical Models
    - Risk Analysis
    - Risk-Resilience Informed Decisions
  - Scenarios
    - Interactive Planning
    - Satisficing Solutions
    - Resilient Alternatives
  - Yellow Zones
    - Table 2
    - Complex, Apply Soft Systems Thinking Table 3
  - Chaos
    - Disorganized Retreat
  - Red Zones
    - Table 2
Example 2 Technical Problem

**Figure 2**

1. Coastal Community
2a. Subsystems Infrastructure
   - 2b. Energy
   - 2b. Water
   - 2b. Waste
   - 2b. Transport
   - 2b. Landscape
   - 2b. Information
2c. Regional authority for collecting and treating wastewater from local jurisdictions
3. Jurisdictions - Local authorities for collecting local wastewater.

**Figure 4**

- Edge of Chaos
- Zone of Chaos
- Zone of Complexity
- Close to Agreement
- Close to Certainty
- Far from Agreement
- Far from Certainty

**Figure 5**

- Type Problem Situation
  - Yellow Zones
    - Complicated, Apply Hard Systems Thinking Table 3
    - Mathematical Models
    - Risk Analysis
    - Risk-Resilience Informed Decisions
  - Complex, Apply Soft Systems Thinking Table 3
    - Scenarios
    - Interactive Planning
    - Satisficing Solutions
    - Resilient Alternatives
- Red Zone
  - Chaos
  - Disorganized Retreat
On-Going Projects

• Recent storms has help the City of VA Beach accept a worldview.

• Boston shifted from brute resistance to some forms of retreat; making room for flooding.

• New York City Big U, is it still struggling with a worldview? (28 to 33 minutes in video).

Conclusions

• Simplified Process
• Disciplined way of structured thinking
• A graph to aid in determining hard or soft thinking
• A kind of thinking to plan capital improvement investments compatible with an uncertain future.
• A way to map the future to assess if moving toward resolution or toward chaos.

“For every complex problem there is an answer that is clear, simple and wrong.” H. L. Mencken

Q & A