PREPTalks
New perspectives for emergency managers

Discussion Guide
Using Complex Adaptive Systems Thinking to Understand Community Interdependencies
Dr. Charles "Chick" Macal

PrepTalks Discussion Guides provide a framework for community leaders to translate insights from the PrepTalk into community planning and outreach. Community leaders can use the PrepTalks materials at meetings, workshops, and conferences to address critical emergency management topics with whole community partners.

Using Complex Adaptive Systems Thinking to Understand Community Interdependencies

Dr. Macal is the Chief Scientist of Argonne National Laboratory's Resilient Infrastructure Initiative, where he leads a team of interdisciplinary researchers developing new computational models and simulations for infrastructure interdependency analysis, planning, and resilience. Dr. Macal is a globally recognized leader in the field of agent-based modeling and simulation, focusing on the social and behavioral components of socio-technical systems.

In his PrepTalk, Dr. Macal explains the elements of complex adaptive systems, the tools used to analyze systems, and how systems thinking can improve emergency management.

Partners for the Discussion

> *We need more systems thinking and we need more systems doing in this entire field of emergency preparedness.*
>
> — Dr. Chick Macal

Dr. Macal urges emergency managers to apply systems thinking to the day to day work of preparing to respond and recover from disasters. He recommends conducting a network analysis to identify important stakeholders and the communication channels needed for effective decision making. Begin the discussion with your core planning team and expand it to include stakeholders from the whole community. Use this Discussion Guide to apply the principles of systems thinking to improve preparedness, mitigation, response, and recovery decisions in your community.

Discussion Topics

Topic 1: Understanding Complex Adaptive Systems and Systems Thinking

Dr. Macal explains that complex adaptive systems are networks of dynamic interactions and that emergency managers need to be "systems thinkers" to be more effective. Being a systems thinker means understanding individual interactions, as well as the attributes of the interconnected system – in other words, seeing the tress and the forest simultaneously. As systems thinkers, emergency managers can improve decision-making and can identify and execute interventions that are helpful, not counter-productive.

While complex adaptive systems may not be well known by emergency managers, Dr. Macal highlights that the language of complex adaptive systems is familiar, including terms like:

> *A **complex adaptive system** consists of a large number of interconnected components (agents) that interact, adapt, learn.*
>
> — Dr. Chick Macal

- Tipping Point, Turning Point
- Non-linear, Phase Change, Sea Change
- Feedback, Blowback
- Domino Effect, Cascades
- Emergence, Collective/Distributed Intelligence, Swarm Behavior
- Small World, Six Degrees of Separation, "Kevin Bacon" Game
- Endogenous (inside the system) vs. Exogenous (determined from outside the system)
- Top Down vs. Bottom Up.

If you have used these terms in conversation, you probably were discussing a system, and that's not surprising. We are all part of complex adaptive systems: socially, at work, and in our environments. In emergency management, the important complex adaptive systems to consider are critical infrastructure/lifeline systems and multi-agency coordination during response and recovery.

Complex adaptive systems can also be overlapping, redundant, and wholly part of a larger system or a system of systems. Understanding the systems that communities rely on will help emergency managers understand that the consequences of intervention could be far more widespread than the immediate problem being solved. As Dr. Macal explains, systems thinkers think outside their job description and outside the box of their organization to see the bigger picture.

Ways to Visualize Complex Adaptive Systems

Complex adaptive systems can be visualized through several analytical methods, depending on the amount of time, type of data, and overall goals of the analysis.

> *We are all part of complex adaptive systems. We need to understand them to anticipate the outcomes of our actions, and we need to consider the behavior of people and of decision-makers in the process.*
>
> — Dr. Chick Macal

- **Network Analysis**: Draw a picture of the important decision-making organizations that shows how they are connected and how they exchange information. Network Analysis include nodes, links, and flow.
- **Causal Modeling/System Dynamics**: Look at the factors that produces a system's behavior, step by step.

- **Optimization**: Capture the objectives, constraints, and resources of the systems and how they work together in an inter-woven framework.
- **Agent-based modelling**: Use a bottom-up approach, modeling the actions of individuals within a population and their decision-making behaviors.

Dr. Macal believes that in the future, new tools, models, and analytical approaches will improve our ability to understand and analyze complex adaptive systems. Increased computing power and advances in artificial intelligence, data analytics, and machine learning will allow behavior to be predicted and produce better outcomes to support decision-making.

Analyzing Lessons Learned to Improve Planning

Dr. Macal recommends that we build a repository of the recurring questions and challenges that arise in emergencies, the ways people behave in emergencies, and the systems-impact of response and recovery decisions. By building a repository, indexed for analysis, we can capture cross-cutting lessons learned from multiple disasters. The techniques used to assess complex adaptive systems can be employed to aggregate this data and provide evidence-based information to improve planning and future responses.

> *What's written down in the plans as an organizational structure of decision making can be completely different from what actually occurs in the real world in the event of a disaster or an emergency.*
>
> — Dr. Chick Macal

Questions for Discussion

- ❑ Are you a systems thinker? Systems thinking requires a shift from seeing individual elements with a linear cause and effect to seeing an entire system with interrelated nodes, links, and flows.
- ❑ Conduct a network analysis. Doing a network analysis exercise has immediate value because participants quickly identify gaps. Often these gaps involve realizations that decision makers don't have important relationships with key stakeholders, or won't have timely access to critical information, or don't have adequate resources.
  - ❑ What are the requirements of the system; what is it supposed to do? Consider the stakeholders (nodes) in the system, the people who will be making the decisions. What processes will they follow to arrive at those decisions?
  - ❑ What is flowing through the system – is it information? Money? Energy? A complex adaptive system always has a flow; that's one of the principles. The flow gives the system life; it animates the system.
  - ❑ What are the measures or metrics of what the system is supposed to do? How will you know how well the system is functions?
  - ❑ What are the resources that are needed to allow the system to move forward?

- ❑ Catalog past decisions and actions. Jurisdictions should record the reoccurring issues that arise during disasters in their community and document how these problems were addressed. This will help communities become learning organizations, building on past experiences.

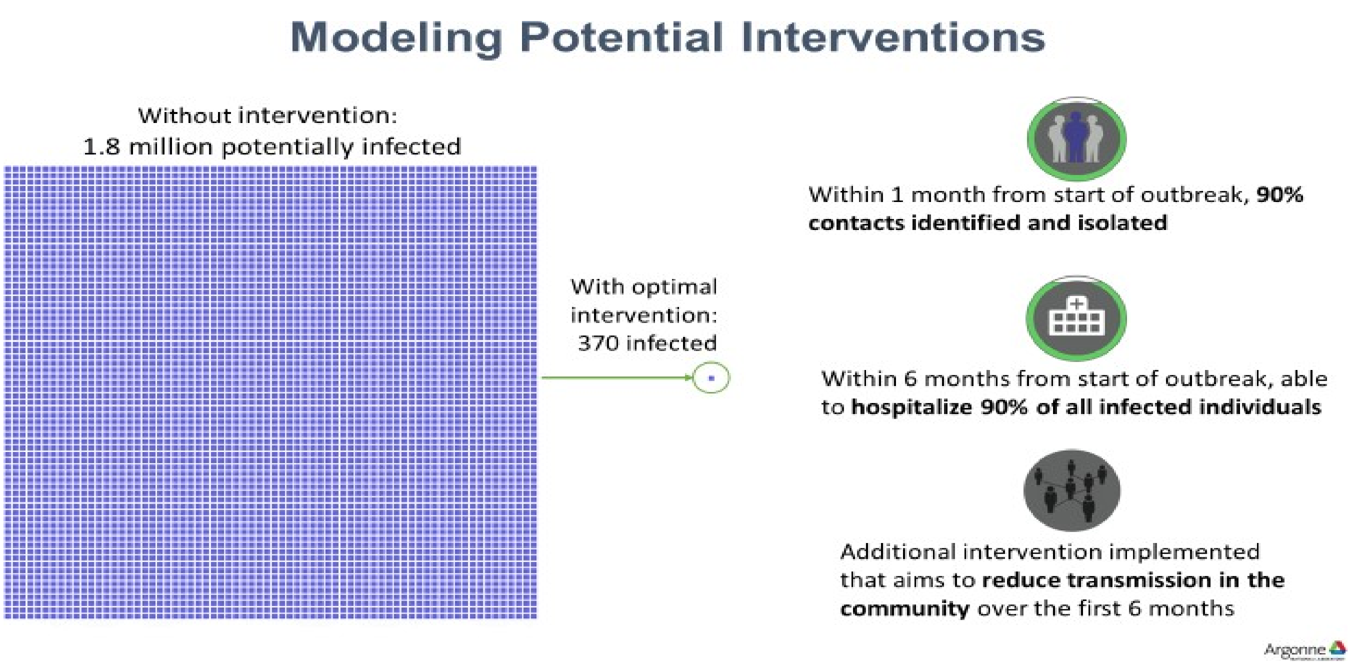
Topic 2: Ebola Outbreak Case Study

Dr. Macal shares the dramatic example of his experience modeling a potential Ebola outbreak in Chicago. The analysts used agent-based modeling to display the social contacts of individuals (agents) throughout their day under thousands of different scenarios. The analysts were able to identify interventions that reduced the potentialnumber of people affected in Chicago from millions to hundreds usingoptimal public health interventions.

In addition, agent-based modeling allowed the researchers to determine the existing capacity of care for potential Ebola patients, based on resources, space, and health care personnel. At the time of the analysis in 2014, the total capacity for caring for Ebola patients in Chicago was only eight patients – far below the forecasted numbers ofinfected patients in a potential outbreak. [See Dr. Sheri Fink's PrepTalk on Triage, Ethics, and Operations: Healthcare Emergency Preparedness and Response to learn more about managing scarce resources healthcare event.]

Essential Elements of Good Systems Analysis and Analysts

- *Representation*
- *Requirements*
- *Stakeholders*
- *Process*
- *Flows*
- *Measures*
- *Resources*
- *Objectives*



Source: Dr. Chick Macal PrepTalk

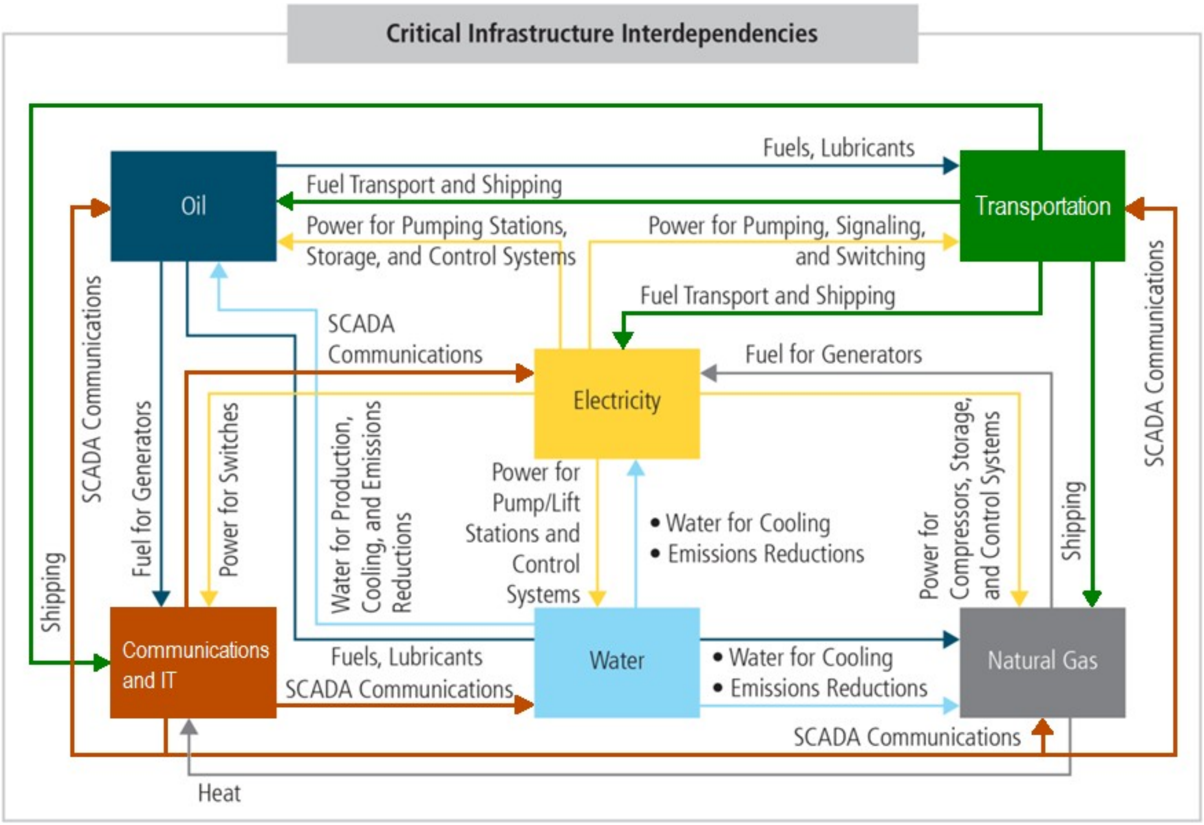
Questions for Discussion

- ❑ Think about where surgically timed and placed interventions could affect the entire system more effectively, including injections of information and resources.
- ❑ Assess interventions from a systems perspective. Small interventions can have big effects. Consider the whole system when making decisions to ensure that interventions benefit the system and move the system to a more desirable or more useful state.

Topic 3: Critical Infrastructure Interdependencies Case Study

Dr. Macal demonstrates how critical infrastructures, including oil, transportation, electricity, communications/IT, water, and natural gas, are a complex adaptive system with many interdependencies.

He explains how research using multiple scenarios to identify infrastructure vulnerabilities has shown that a disturbance in the electric power grid can lead to a shutdown in the natural gas system, which in turn, disrupts any augmented electric power usinggenerators. Natural gas is an important source of fuel for power generation, so the interdependency between gas and electric power creates a loop in which a disruption in one infrastructure candisturb another infrastructure and have cascading impacts over time. Disruptions in one locations can even affect people four or more states away.



Source: Dr. Chick Macal PrepTalk

Another example of interdependencies between infrastructures is that electric power systems supply electricity for water pumps, which are necessary to bring water to a community, and water is needed to coolelectric power plants.

Supply chains also have significant dependencies and interdependencies, with potentially catastrophic cascading effects if supplies are disrupted. [See PrepTalks by Dr. Yossi Sheffi and Dr. Jarrod Goentzel onPrivate Sector Supply Chain Resilience and Emergency Management.]

> *The biggest interdependency we have now in our society is the one between the supply of natural gas [that relies on electric power] and the electric power systems across the U.S.*
>
> — Dr. Chick Macal

Questions for Discussion

- ❑ Can you identify multiple systems in which you operate? Consider infrastructure and lifeline systems.
- ❑ What critical infrastructure interdependencies exist in your community? Use a network analysis or other visualization technique to map the interdependencies and identify the nodes, links, and flows to make sure you are ready to support response and recovery of these infrastructure systems after a disaster.

For the companion Facilitator Slides and Resource List for this PrepTalk, visit:
https://www.fema.gov/blog/preptalks-dr-macal-using-complex-adaptive-systems-thinking