A MODEL OF COLLECTIVE-ADAPTIVE RESPONSE TO CASCADING DISASTERS

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ABSTRACT

This work introduces a novel Collective-Adaptive Disaster Response (CADR) model for analyzing the dynamics of institutional collective action (ICA) in response to various cascading disasters (e.g., pest infestation, wild fires, and epidemics, to name a few). Here, we demonstrate the applicability of the CADR model using an illustrative hypothetical case of a pest infestation disaster. It was found that partial resource sharing as a collaborative disaster response scheme among local government units (LGUs) provide more benefit than the conventional fragmented response scheme. The proposed model promotes the synchronized collaboration of LGUs as a strategy against cascading disasters.

INTRODUCTION

The Gaps

Collective action is vital in responding to cascading disasters – disasters whose effects spread through space and time. Although several conceptual frameworks have been developed to formalize institutional collective action (ICA) in the context of emergency situations [1], majority of these frameworks are qualitative and offer limited detail about the dynamics involved in the phenomenon being described. Furthermore, limited attention is provided in the current literature in quantitatively modeling the dynamics of ICA in the context of cascading disasters.

The Objectives

The objective of this work is to develop a mathematical representation that synthesizes the factors involved in ICA in the context of disaster response. The modeling work also intends to represent several adaptive features of local government units (LGUs) to crisis situations involving cascading disasters. The model introduced here is the Collective-Adaptive Disaster Response (CADR) model. The efficacy of the CADR model is tested here as well.

METHODOLOGY

The CADR Model

There are four equations that define the CADR model. Equation (1) defines the number of susceptible assets, (2) defines the disrupted assets, (3) defines the capacity of an LGU to address the disaster, and (4) defines the funds from which that capacity is sourced.

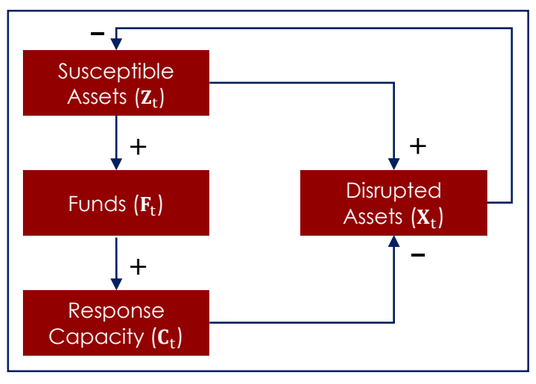

Fig. 1. Basic CADR Conceptual Framework

$$\mathbf{Z}_{t+\Delta t} = \mathbf{Z}_t - (\mathbf{X}_{t+\Delta t} - \mathbf{X}_t) \quad (1)$$

$$\mathbf{X}_{t+\Delta t} = [\bar{\mathbf{P}}_{t+\Delta t}\mathrm{diag}(\mathbf{Z}_t)]^T\mathbf{J} + \bar{\mathbf{X}}_{t+\Delta t} \quad (2)$$

$$\mathbf{C}_{t+\Delta t} = \bar{\mathbf{C}}^+_{t+\Delta t} + \bar{\mathbf{Y}}^+_{t+\Delta t} + \bar{\mathbf{F}}^+_{t+\Delta t} - \bar{\mathbf{Y}}^-_{t+\Delta t} \quad (3)$$

$$\mathbf{F}_{t+\Delta t} = \mathbf{F}_t - \bar{\mathbf{F}}^+_{t+\Delta t} + \mathbf{N}_{t+\Delta t} \quad (4)$$

The equations are formulated in such a way that follows the framework in Fig. 1. The interrelationships of the four "stocks" (in systems dynamics terms) form part the collaborative and adaptive aspect of the CADR model (see conference paper for details). Here, ICA is represented in the form of collaboration among LGUs in responding to cascading disasters via resource sharing.

The Hypothetical Case

To demonstrate the CADR model, a hypothetical case of a pest infestation disaster is presented. The parameter values used for the simulation of the case Is presented in Table 1.

Table 1. Parameter Values and Initial Conditions

No.	$\mathbf{X}_0$ (acres)	$\mathbf{Z}_0$ (acres)	$\mathbf{C}_0$ (10^3 PhP)	$\mathbf{F}_0$ (10^3 PhP)	$\mathbf{G}$ (10^3 PhP)	α	τ
LGU 1	1.0	1,000.0	300.0	13,680.0	125.0	0.5	0.01
LGU 2	1.0	500.0	150.0	28,620.0	90.0	0.5	0.01
LGU 3	1.0	250.0	75.0	10,800.0	170.0	0.5	0.01

RESULTS AND DISCUSSIONS

Key Findings

The findings of this work are summarized in Fig. 2.

- Collaboration of LGUs by means of resource sharing delay the impact of the cascading disaster.
- Collaboration expedites the recovery disrupted LGUs.
- There exist a threshold in which the degree collaboration is optimal. Beyond the said threshold, collaboration becomes counter productive.
- Collaboration becomes counter productive when it renders an LGU vulnerable to potential disruptions that can cascade from neighboring LGUs.

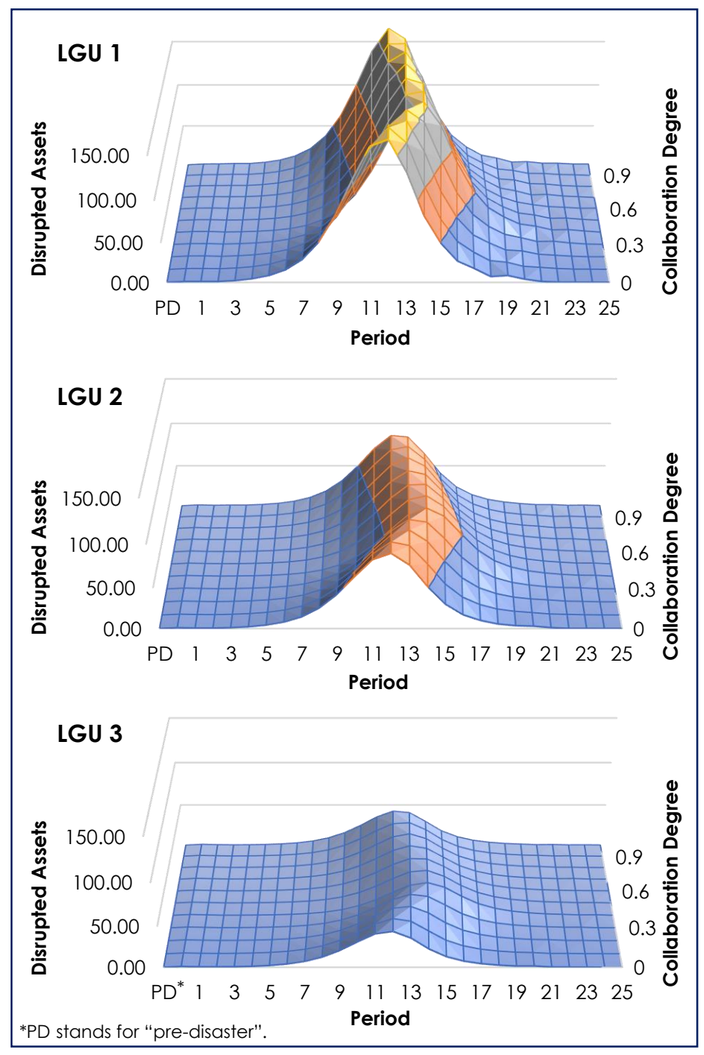

Fig. 2. Disrupted assets over different collaboration degrees per LGU over time. PD stands for "pre-disaster".

- For instance, when the collaboration degree is equivalent to one, it entails that an LGU is willing to share 100% of its surplus resources to neighboring disrupted LGUs. However, in the succeeding periods, such a strategy would render the providing LGU at risk of potential disaster cascades coming from the very LGUs that it helped. Thus, while collaboration is essential, it should be in partial implementation to avoid counter productive outcomes.

CONCLUSIONS

- In conclusion, the CADR model elucidates the dynamics of ICA via collaboration of LGUs in addressing cascading disasters. Here, the said dynamics are shown through a hypothetical case of a pest infestation disaster.
- It was found that partial resource sharing as a collaborative disaster response scheme among LGUs provide more benefit than the conventional fragmented response scheme.
- The CADR model introduced here can become basis for a system to synchronize LGUs in responding to cascading disasters. This work establishes the mathematical framework for such a system and the example presented here (i.e. the pest infestation disaster) demonstrates its potential socio-economic benefit.